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1.0 EXECUTIVE SUMMARY

The Tacoma LNG Project is to be located in the Port of Tacoma in Tacoma, Washington and is an LNG facility subject to the siting requirements of 49 CFR 193 and by reference NFPA 59A (2001). The siting requirements cover the methods and means to determine design spills, spill conveyance, impoundment sizing, and thermal radiation exclusion zones from ignition of design spills into impoundments such that a public hazard does not extend beyond the bounds of the property. Additionally the siting requirements address flammable vapor dispersion exclusion distances to preclude a flammable vapor mixture from a credible design spill reaching a property line that can be built upon.

Calculations supporting the siting requirements have been produced for the Tacoma LNG Project. Design spills have been determined in accordance with 49 CFR 193, and impoundment systems have been sized accordingly. Thermal exclusion zones from impoundment fires have been assessed and are in accordance with 49 CFR 193.

Vapor dispersion analysis has been performed for credible spill scenarios identified within the facility. The resulting flammable vapor exclusion distances do not extend beyond a property line that can be built upon.

Vapor cloud explosion analysis, as currently required by PHMSA, has been performed for credible design spills of reactive vapors into potentially confined and/or congested areas of the facility. Damaging overpressure levels of 1 psi were determined to remain within the property boundary and off of occupied buildings within the facility.

2.0 INTRODUCTION

2.1 Purpose

An LNG liquefaction facility is proposed to be constructed in the Port of Tacoma in Tacoma, WA. LNG will be liquefied onsite, stored, and subsequently bunkered on ships, loaded onto trucks, or regasified. The facility is to be built in accordance with 49 CFR 193 and NFPA 59A (2001).

This report documents the studies and calculations performed to determine safe plant layout and siting requirements for the Tacoma LNG facility as related to hazardous spill control and containment. This includes the calculations and results for impoundment sizing, radiant heat flux exclusion distances, vapor dispersion distances, and Vapor Cloud Explosion (VCE) analysis for the Tacoma LNG Facility.

Design spills and impoundment sizing are determined per the requirements of NFPA 59A (2001) as referenced by 49 CFR 193 and interpreted in the Pipeline & Hazardous Materials Safety Administration (PHMSA) FAQ on LNG Facilities. Radiant heat flux and vapor dispersion calculations are per the requirements of NFPA 59A (2001) and 49 CFR 193. VCE calculations are per the interpretations documented in the PHMSA FAQ on LNG Facilities.

2.2 Scope

Per Federal Regulations and industry standards, ensuring adequate control and containment of hazardous spills requires the following:

- Identifying design spill scenarios
- Determining design spill flow rates
- Sizing spill impoundments
- Modeling vapor dispersion of flammable material design spills
- Modeling thermal radiation heat flux from ignited spills
- Modeling vapor cloud explosion of flammable material design spills

This report describes the basis and results for each analysis undertaken to fulfill the points above.

3.0 REFERENCES

3.1 Codes and Standards

49 CFR Part 193	Liquefied Natural Gas Facilities: Federal Safety Standards
NFPA 59A (2001 ed.)	Standard for the Production, Storage and Handling of Liquefied Natural Gas (LNG)

3.2 Project Documents

186512-000-PI-01-000001	Rev. P	Overall Plot Plan Main LNG Plant
186512-000-CV-01-000003	Rev. D	Site Plan – Main LNG Plant with Blair Dock and Hylebos Dock
186512-000-PR-01-000101	Rev. B	Process Flow Diagram – Liquefaction
186512-000-PR-01-000102	Rev. B	Process Flow Diagram – LNG Loading & Vaporization
186512-000-PR-01-000103	Rev. B	Heat & Material Balance – Liquefaction & Loading
186512-000-PR-01-000104	Rev. B	Heat & Material Balance – Holding & Vaporization

186512-000-SE-01-000011	Rev. D	Thermal Exclusion Zone Plan – Main LNG Plant with Blair Dock (TOTE) and Hylebos Dock

3.3 Other

PHMSA Website – LNG Facility Siting	LNG Facility Siting Application Requirements: Frequently Asked Questions http://primis.phmsa.dot.gov/lng/faqs.htm
PHMSA Website – LNG Facility Siting	LNG Facility Siting: Documents Nominal Failure Rate Table 1; February 11, 2015 http://primis.phmsa.dot.gov/lng/documents.htm

4.0 DEFINITIONS

Term/Acronym	Definition
NG	Natural Gas
LNG	Liquefied Natural Gas
MR	Mixed Refrigerant
FG	Fuel Gas
NFPA	National Fire Protection Association
PHMSA	U.S. DOT Pipeline and Hazardous Materials Safety Administration
Exclusion Zone	Areas within which certain activities or building construction is limited. Exclusion zones are centered on a hazardous spill or spill impoundment, and pertain to both fire radiant heat flux limits and flammable vapor cloud concentration limits.

5.0 DESIGN SPILL SCENARIO CALCULATIONS

Design spills within the plant have been assessed according to the requirements of 49 CFR 193.2051, NFPA 59A (2001) and the interpretations set forth by PHMSA (see References). As the LNG storage tank is full containment there is no tank design spill criteria.

Per Table 2.2.3.5 of NFPA 59A (2001), design spill scenarios for vaporization, process or LNG transfer areas must be assessed and impoundment exclusions zones analyzed. The design spill description given in NFPA 59A (2001) is stated as, “The flow from any single accidental leakage source,” which is applied over a ten minute duration. PHMSA has further defined what failure types must be assessed and what probabilities must be applied to determine the validity of each design spill scenario.

5.1 Identification of Piping Spill Scenarios

Per PHMSA direction, a Piping Inventory Table was developed for the plant and is included in Appendix A. The Table lists every line in the plant 2 inches in diameter or larger that contains hazardous/flammable fluids. Each of these lines was assessed against multiple failure scenarios defined in the Nominal Failure Rate Table, provided by PHMSA. These line failure criteria are transcribed in Table 1.

Min. Pipe Size (in)	Pipe Size Range NPS	Failures per year of operation, per meter of pipe			
		Piping (P1): Catastrophic Rupture	Piping (P2): Release from hole w/ Effective	Piping (P3): Release from hole w/ Effective	Piping (P4): Release from hole w/ Effective
2	2" ≤ d < 6"	5.0E-07			2.0E-06
6	6" ≤ d < 12"	2.0E-07	4.0E-07		7.0E-07
12	12" ≤ d < 20"	7.0E-08	2.0E-07	4.0E-07	5.0E-07
20	20" ≤ d < 40"	2.0E-08	1.0E-07	2.0E-07	4.0E-07

Table 1: Line Failure Scenario and Probabilities (from PHMSA Nominal Failure Rate Table).

Probabilities for each failure scenario are calculated from the diameter and length of the line section. When the failure probability exceeds 3 x 10^{-5} failures/year, the threshold defined by PHMSA, the failure is considered credible and requires further analysis. The failure probability calculations are contained in Appendix A, and credible line failures identified by this method are highlighted and denoted on the right hand side of the table. Credible failure scenarios requiring analysis are summarized in Appendix B. Further discussion on the election of failure scenarios to include in Appendix B is provided in section 8.3.

5.2 Identification of Equipment Spill Scenarios

Per PHMSA direction, an Index of Equipment Containing Hazardous Materials was developed for the plant and is included in Appendix C. The Index lists all major equipment in the plant that contains hazardous or flammable fluids, including vessels, pumps & compressors, heat exchangers, and hoses. The Index also includes the estimated quantity of liquid held in each piece of equipment during normal operation.

Spills from the individual pieces of equipment were assessed against the total spill volumes in the line failure scenarios listed in Appendix B. The quantities spilled in the line failure scenarios were significantly larger than the quantity of liquid held in the equipment listed. This generally precluded the need to analyze equipment failures, as the resulting exclusion zones are much smaller than those produced by line failure scenarios.

The exception to this approach is the MRL Condensate Separator (V-204). The piping analysis did not produce large credible MR liquid line failure scenarios, so the MRL Condensate Separator vessel was included in the vapor dispersion study set. Per the Nominal Failure Rate Table, a catastrophic rupture scenario and 0.4 inch diameter hole release were assessed.

Failures of the refrigerant storage vessels (V-205, V-206, V-207 and V-208) and the heavies storage vessel (V-802) were not considered for design spill determination as these vessels will be mounded and contained inside a concrete vault.

5.3 Spill Flow Rate Calculations

For each credible failure scenario listed in Appendix B, an analysis was performed to determine the design spill flow rate. Where more than one credible scenario was identified for a single line, the most conservative case was selected. The resulting spill mass flow rates for each case are summarized in Appendix B.

Spill flow rates were determined by considering the limitations of pumping equipment and the dynamics of the release scenario. Where the leak supply is being fed by a pumped source, such as cases involving the in-tank LNG pumps, the flow rate was pushed to the run-out flow rate of the operating pump(s). PHMSA requires the consideration of pump run-out in defining spill scenarios. Calculations of spill flow rates fed by a pumped source are included as Appendix D

Where the leak is being fed by a plenum or where the leak size restricts flow to less than the full source supply, the flow rate was determined using Det Norske Veritas (DNV) Phast software, Version 7.01. Summary plots for each case are included in Appendix E.

6.0 IMPOUNDMENT SIZING CALCULATIONS

6.1 LNG Tank Impoundment Sizing

The Tacoma LNG Facility includes one (1) full containment LNG Storage Tank of 8,000,000 gallons capacity. The inner tank has a maximum liquid volume of 8,430,000 gallons at a design liquid level of 86'-3". Secondary containment for the tank is provided by a full containment concrete outer tank.

Per 49 CFR 193.2181, each impounding system serving a single LNG storage tank must have a minimum liquid impoundment capacity of 110 percent of the LNG Storage Tank's maximum liquid capacity. The outer tank serves as the impoundment, and has sufficient capacity to meet the requirement listed above. Verifying calculations are included in Appendix F.

The total impoundment volume, less displacement allowances, is 10,770,000 gallons, which provides more than 27% excess capacity beyond the LNG Storage Tank's maximum liquid capacity.

6.2 Process Spill Impoundment Sizing

Credible LNG spills within the facility are directed to below grade open top concrete spill trenches, which convey spills to containments consisting of below grade open top concrete sumps. Impounding areas, provided to serve vaporization, process, or LNG transfer areas shall have a minimum volumetric capacity equal to the greatest volume of LNG or flammable liquid that can be discharged into the area during a 10 minute period from any single accidental leakage source. The following impounding sumps are provided and sized to accommodate these spills.

6.2.1 Process Area Spill Sump

For full containment LNG containers with over-the-top fill and no penetrations below the liquid level a design spill scenario is the largest flow from any single line that could be pumped with the container withdrawal pump(s) at rated capacity. The spill duration is considered to be 10 minutes based on a facility with surveillance and shutdown capabilities upon detection of a spill. Three LNG in-tank pumps are provided for the facility and may be operated simultaneously under future sendout scenarios, therefore all three pumps' capacities are considered.

PHMSA direction requires the consideration of pump run out in process design spill calculations. A credible failure scenario exists for the sendout header from the tank (line 10"-LNG-4007) that can potentially spill the run out flow from all three pumps. Therefore, the spill impoundment sump has been sized for this capacity.

The process area spill sump serves spills emanating from the LNG tank platform, the liquefaction area, the ex-tank sendout pump area, the vaporizer area and the truck loading station.

- Pump Runout Capacity 1,630 gpm
- Spill Duration 10 minutes
- No. Pumps Running 3
- Spill Volume 48,900 gallons

PHMSA direction also requires the consideration of pipe de-inventory when determining spill quantity. The Process Area Spill Sump is sized to accommodate the spill volume above as well as de-inventory of the LNG supply header (line 10"-LNG-4007), the TOTE dock supply header (line 10"-LNG-4017) and the Hylebos dock supply header (line 8"-LNG-4023). Spill capacity and volume

calculations are included as Appendix F, and the resulting cylindrical impoundment sump has the following dimensions:

- Diameter 22.25 ft
- Gross Depth 20.5 ft
- Usable Depth 19 ft
- Usable Volume 55,300 gallons

6.2.2 Hylebos Loading Spill Sump (Future)

LNG spills emanating at the Hylebos jetty are collected in a concrete curbed area under the arms and piping which gravity drains to a concrete trench that runs the length of the jetty back ashore. The trench is directed to the Hylebos Loading Sump. The spill duration is considered to be 10 minutes based on a facility with surveillance and shutdown capabilities upon detection of a spill. Two LNG in-tank pumps operate during marine loading operations.

- Pump Runout Capacity 1,630 gpm
- Spill Duration 10 minutes
- No. Pumps Running 2
- Spill Volume 32,600 gallons

PHMSA direction also requires the consideration of pipe de-inventory when determining spill quantity. The Hylebos Loading Sump is sized to accommodate the spill volume above as well as de-inventory of the LNG supply header (line 10”-LNG-4007), the TOTE dock supply header (line 10”-LNG-4017) and the Hylebos dock supply header (line 8”-LNG-4023). Spill capacity and volume calculations are included as Appendix F, and the resulting cylindrical impoundment sump has the following dimensions:

- Diameter 22.25 ft
- Gross Depth 15 ft
- Usable Depth 13.5 ft
- Usable Volume 55,300 gallons

6.2.3 TOTE Bunkering - Facility and Dock Side

6.2.3.1 Spill Sumps

The supply line from the facility to the TOTE bunkering dock runs from above ground pipe rack into a transition pit, through an underground pipeline into a second transition pit, and onto above ground sleepers to the bunkering dock. The transition pits serve as LNG impoundments on either end of the underground supply line.

On the facility side, the supply line to TOTE runs on an E-W pipe rack. The area underneath is paved to drain away spills to a trench that runs to the Process Area Spill Sump. The facility side TOTE spill sump (i.e. transition pit) only serves the piping in the pit itself.

On the TOTE dock side, the area underneath the supply line and loading arm is paved to drain away spills to a trench that runs to the TOTE dock Spill Sump. The TOTE dock spill sump (i.e. transition pit) serves as impoundment for all spills at the dock side facility.

The spill duration is considered to be 10 minutes based on a facility with surveillance and shutdown capabilities upon detection of a spill. The mass spill rate is the same for both impoundments, and is based on the credible leak scenario of a 1/3 diameter hole (3.33") in the supply line.

- Mass Spill Rate 655,710 lb/hr
- Spill Duration 10 minutes
- Total Spill Mass 110,952 lbs
- Total Spill Volume 30,380 gallons

PHMSA direction also requires the consideration of pipe de-inventory when determining spill quantity. The TOTE Bunkering Spill Sumps are sized to accommodate the spill volume above as well as de-inventory of the LNG supply header (line 10"-LNG-4007), the TOTE dock supply header (line 10"-LNG-4017), the TOTE dock-side line (line 10"-LNG-4062) and the Hylebos dock supply header (line 8"-LNG-4023). This assumes a break at a low point in the spill sump that would allow gravity drainage of all these lines. Spill capacity and volume calculations are included as Appendix F, and the resulting impoundment has the following dimensions:

- Length 18.86 ft
- Width 14.6 ft
- Gross Depth 20 ft
- Usable Depth 18.5 ft
- Usable Volume 38,100 gallons

6.2.3.2 Underground Pipeline

As described above, LNG is supplied from the facility to the TOTE dock via an underground pipeline. All underground process piping between the TOTE dock and the LNG facility are full containment vacuum jacketed pipe, and are run inside in a nitrogen purged tunnel encasement. Should a leak occur in the inner pipe, the fluid will be contained by the outer pipe jacket and the system will have a relief path back to the LNG storage tank. Due to this configuration of containment, the underground lines are not included in the assessment of credible spill scenarios for atmospheric vapor dispersion.

6.2.4 Trenches & Curbing

Any liquid spills in the process area or along the pipe racks will fall into curbed containment areas, and will be conveyed to the spill sumps by a below grade open top concrete transmission trenches. The preliminary layout of spill containment and conveyance is shown on Spill Containment Plan Drawings 186512-000-CV-08-000101 through 000103, which are included in Appendix G.

Trenches have been sized to convey the maximum design liquid spill rates for the areas they serve. The trenches will be 2 ft wide with a slope towards the respective sump of 0.2% (2 ft fall in 1,000 ft run). Trench depths vary, and are stepped to prevent backflow of spills into unaffected sections of the trench system. Calculations for trench dimensions and slope can be found in Appendix F.

7.0 RADIANT HEAT FLUX CALCULATIONS

The following sections outline the exclusion zone requirements for an impoundment fire, a description of the analysis conducted, and an assessment of the results.

7.1 Requirements

Per 49 CFR 193.2057, each LNG container must have an exclusion zone in accordance with section 2.2.3.2 of NFPA 59A (2001). Per Section 2.2.3.2 of NFPA 59A (2001), the exclusion zones are based on thermal radiation flux limits for an impoundment fire scenario. The three radiant heat flux limits are listed in Table 2.

Thermal Radiation Flux Limit ($Btu/hr/ft^2$)	Exposure Description
1,600	The nearest point located outside the owner's property line that, at the time of plant siting, is used for outdoor assembly by groups of 50 or more persons for a fire over an impounding area at full volume containing LNG
3,000	The nearest point on the building or structure outside the owner's property line that is in existence at the time of plant siting and used for occupancies classified by NFPA 101, Life Safety Code, as assembly, educational, health care, detention and correction, or residential for a fire in an impounding area at full volume containing LNG
10,000	At a property line that can be built upon for a fire in an impounding area at full volume containing LNG

Table 2: Radiant Heat Flux Limits to Property Lines and Occupancies

7.2 Environmental Parameters

In accordance with 49 CFR 193.2057(b) & (c), radiant heat flux distances are calculated using:

i) the wind speed producing the maximum exclusion distances, except for wind speeds that occur less than 5% of the time based on recorded data for the area; and

ii) the ambient temperature and relative humidity that produce the maximum exclusion distances, except for values that occur less than 5% of the time based on recorded data for the area.

Meteorological data from ASHRAE Handbook – Fundamentals 2013 for Tacoma/McChord AFB (#742060) is used for the calculations in this report. The data sheet and a summary of climatic data derivations are provided in Appendix M.

The following is a summary of weather conditions to be used for the radiant heat flux analysis:

- Wind Speed 15.6 MPH down to 4.5 MPH
- Ambient Temperature 31.95 •F
- Relative Humidity 54.7%

7.3 Radiant Heat Flux – LNG Tank Fire

The LNG tank at the Tacoma LNG facility is a full concrete containment tank with over-the-top fill and no penetrations below the liquid level. The secondary containment system is the outer concrete tank. For radiant heat flux distance calculations, the outer roof is considered to have failed with a tank top fire having the same radius as the inner diameter of the concrete. LNGFIRE3 is recognized by 49 CFR 193 and NPFA 59A as a computer model for calculation of the radiation heat flux limits

from LNG fires described in NFPA 59A. LNGFIRE3 was run with the meteorological data presented in section 7.2 and the following tank parameters:

- LNG Tank Concrete Inner Dia 135.5 FT
- LNG Tank Height 118.5 FT

The output from LNGFIRE3 is included in Appendix H. Maximum radiant heat flux limits occur at the maximum wind speed at all flux levels.

The radiant heat flux limit isopleth distance for the LNG storage tank fire at a target elevation of 0 ft (grade) is:

Radiant Heat Flux Limit (BTU/hr-ft^2)	Distance from Center of Pool (ft)
1,600	550.3

The radiant heat flux exclusion zone is overlaid on the facility plot plan on drawing 186512-000-SE-01-000011 Rev D included in Appendix H, which shows that the radiant heat flux limits meet the requirements of NFPA 59A (2001).

7.4 Radiant Heat Flux – Process & Hylebos Spill Sumps

The Process Area Spill Sump and the Hylebos Loading Spill Sumps are described in section 6.2.1 and 6.2.2 respectively. Both impoundments have the same plan geometry, therefore the radiant heat flux isopleths are the same. For radiant heat flux distance calculations, the sumps are conservatively considered to be filled with product and have caught fire. LNGFIRE3 was run with the meteorological data presented in section 7.2 and the following parameters:

- Impoundment Diameter 22.25 FT
- Height of Flame Base 0 FT

The output from LNGFIRE3 is included in Appendix H. Maximum radiant heat flux limits occur at the maximum wind speed at all flux levels.

The radiant heat flux limit isopleth distances for the sump fire at a target elevation of 0 ft (grade) are:

Radiant Heat Flux Limit (BTU/hr-ft^2)	Distance from Center of Pool (ft)
1,600	125.7
3,000	105
10,000	75.3

The radiant heat flux exclusion zone is overlaid on the facility plot plan on drawing 186512-000-SE-01-000011 Rev D included in Appendix H, which shows that the radiant heat flux limits meet the requirements of NFPA 59A (2001).

Because of its proximity to the outer tank wall, the heat flux from the Process Sump was also analyzed at varying elevations to ensure that the 10,000 Btu/hr-ft^2 limit is not exceeded at the concrete surface of the tank. The output from LNGFIRE3 is included as Appendix H. The maximum reach of the 10,000 Btu/hr-ft^2 limit occurred at an elevation of 12' and a distance from the center of the pool of 78.2 ft. This is the exclusion zone shown on drawing 186512-000-SE-01-000011 in Appendix H.

7.5 Radiant Heat Flux – TOTE Bunkering Spill Sumps

The TOTE Bunkering Spill Sumps are described in section 6.2.3. Both impoundments have the same plan geometry, therefore the radiant heat flux isopleths are the same. For radiant heat flux distance calculations, the sumps are conservatively considered to be filled with product and to have caught fire. LNGFIRE3 was run with the meteorological data presented in section 7.2 and the following parameters:

- Impoundment Length 18.85 FT
- Impoundment Width 14.6 FT
- Height of Flame Base 0 FT

The output from LNGFIRE3 is included in Appendix H. Maximum radiant heat flux limits occur at the maximum wind speed at all flux levels.

The radiant heat flux limit isopleth distances for the sump fire at a target elevation of 0 ft (grade) are:

Radiant Heat Flux Limit (BTU/hr-ft^2)	Distance from Center of Pool (ft)
1,600	106.7
3,000	91
10,000	68.8

The radiant heat flux exclusion zone is overlaid on the facility plot plan on drawing 186512-000-SE-01-000011 Rev D included in Appendix H, which shows that the radiant heat flux limits meet the requirements of NFPA 59A (2001).

8.0 VAPOR DISPERSION CALCULATIONS

The following sections outline the exclusion zone requirements for flammable vapor dispersion from the credible spill scenarios described above, a description of the analysis conducted, and an assessment of the results.

8.1 Requirements

Per 49 CFR 193.2059, each impounding system serving an LNG container or transfer system must have a flammable vapor dispersion exclusion zone as defined by reference to NFPA 59A (2001), sections 2.2.3.3 and 2.2.3.4. Exceptions to NFPA 59A (2001) are listed in subparts (a), (b) & (c), and include specific requirements for allowable analytical tools, dispersion modeling parameters, and design spill determination.

Per Section 2.2.3.3 of NFPA 59A (2001), an LNG impoundment containing a design spill must be located such that an average concentration of methane in air of 50% of the Lower Flammability Limit (LFL) does not extend beyond the property line that can be built upon.

8.2 Environmental Parameters

Vapor dispersion modeling uses the following parameters specified in NFPA 59A and 49 CFR 193, as well as the annual average temperature taken from the ASHRAE meteorological data sheet for Tacoma/McChord AFB (#742060):

- Stability Class F
- Wind Speed 4.5 MPH (2.01 m/s)

- Average Ambient Temperature 50.9 •F
- Relative Humidity 50%
- Surface Roughness 0.03 m

The data sheet and a summary of climatic data derivations are provided in Appendix M.

8.3 Spill Scenario Assessment for Vapor Dispersion

All credible spill scenarios are identified in Appendix A. The modeling approach for each scenario was assessed based on similarity to other failure scenarios, type of fluid leak, and the necessity for spill conveyance / impoundment. The method of assessment for each spill scenario is recorded in the "Analysis by" column in Appendix A.

Where process conditions and fluid for a spill are similar to another more severe spill scenario, the lesser case is covered by association. Severity is determined based on hole size and location, where larger holes and closer proximity to the property line increase severity. The more severe case is modeled for vapor dispersion and the results (flammable vapor cloud footprint) are assumed to envelope the less severe spill scenario. In this instance, the "Analysis by" column in Appendix A lists the Item Number of the governing case for reference (e.g. Assoc. to #113).

For credible spill scenarios not covered by association and involving vapor releases or non-cryogenic liquids (mixed refrigerant), PHAST version 7.01 software was employed to determine and overlay the downwind distances to the ½ LFL point of a flammable vapor cloud on the plot plan. Version 6.7 of this software package was approved for use under PHMSA Docket No. 2011-0075 for analysis of dispersion from direct releases in any direction, including jetting failures and flashing. The Unified Dispersion Model (UDM) at the core of the program remains unchanged from Version 6.7 to Version 7.01. For these cases, the "Analysis by" column in Appendix A denotes "Phast".

For credible spill scenarios involving cryogenic liquids (LNG) conveyed to open top concrete sumps, FLACS 3D consequence modeling software was employed by GexCon US to determine and overlay the downwind distances to the ½ LFL point of a flammable vapor cloud. This software package was approved for use under PHMSA Docket No. 2011-0101 for determining vapor generation from spills to trenches and impoundments. For these cases, the "Analysis by" column in Appendix A denotes "FLACS".

Spill scenarios involving Normally Not Flowing (NNF) lines such as drains and bypasses were considered to be not credible. The determination of credible leak scenarios using the PHMSA criteria described in section 5.1 inherently considers annual usage; the failure probabilities are couched as "failures per year of operation". Because these lines are not normally in operation, the probability of failure decreases below the threshold of credible failure when duration is factored in. For these cases, the "Analysis by" column in Appendix A denotes "N/A".

8.4 Vapor & Non-Cryogenic Liquid Releases

For qualifying cases as described in section 8.3 vapor dispersion analysis was performed for the credible spill scenarios using PHAST version 7.01 software to determine and overlay the downwind distances to the ½ LFL point of a flammable vapor cloud on the plot plan.

Flammable vapor-gas dispersion distances are determined at the atmospheric conditions stipulated in section 8.2 at an average gas concentration in air equal to 2.5 percent. This represents 50 percent of the lower flammability limit (LFL) of methane in air. For mixed refrigerant spill scenarios, the ½ LFL of the actual mixture has also been assessed.

Results of this analysis, including input and output reports and figures, are included in Appendix E. The analysis shows that none of the flammable vapor cloud exclusion zones extended beyond the property line that can be built upon. Certain cases near the southern terminus of the N-S pipe rack extend beyond the property line and approach, but do not encroach on, 11th Street. To ensure the flammable vapor cloud does not reach 11th Street. a vapor barrier will be installed in this area to

diffuse the release jet and facilitate dispersion. A FLACS vapor dispersion analysis of the scenario was conducted by GexCon US, and shows that the vapor cloud will not reach 11th Street.

8.5 Liquid Releases

As described in section 8.3, failure scenarios for cryogenic liquid lines are analyzed by GexCon US using FLACS software. FLACS analysis is required to accurately model the spill conveyance (trenches) and impoundment and the physical layout of the plant in determining the vapor cloud evolution. The GexCon summary report which details the scenario inputs, outputs and plots, is included as Appendix J.

To accurately assess the full impact of the credible spill scenarios, certain spills were replicated at multiple locations. The liquid spill criteria and case numbers, as well as plot plans indicating the spill locations are provided in Appendix I.

The FLACS analyses show that vapor dispersion exclusion zones for all spill scenarios remain within the property line that can be built upon. Refer to Appendix J for figures showing a plan view of the maximum vapor cloud contours from the liquid design spills.

Note that due to the significant computational time required to perform the FLACS analysis, the model is based on an earlier version of the facility layout (Rev. B of Site Plan drawing 186512-000-CV-01-000003). While the current facility spill trench layout is slightly different than what has been modeled, the spill sizes remain the same, the overall trench lengths are equivalent, and the trench and impoundment sump sizes have remained identical. Layout modifications are comprised of moving portions of the E-W pipe racks/sleepers and spill trenches north and south, with none of the impoundment system moving west, or closer to the property boundary of greatest interest. As a result, it is clear that the modelled spills will remain within the property boundary that can be built upon even if reflected onto the latest Plot layout.

In the TOTE dock area, due to the progression of the Plot Plan the spill trench system shrank significantly by eliminating the N-S run from the dock entrance to the spill impoundment sump. This decreases the vapor cloud footprint as the concrete trench surface area available to vaporize LNG has been reduced. The spill impoundment has moved closer to the TOTE marshalling area. To mitigate this impact, a vapor fence will be installed to sequester the vapor cloud and keep it from reaching the loading ramp for the ship. The results of Scenario 2, which is a larger volumetric spill into an identically sized impoundment, demonstrates the efficacy of the vapor fence in containing the vapor cloud emanating from the sump.

The FLACS analyses assumed that the entire spill quantity remained liquid and was directed into the trench to conservatively model the trench and impoundment sump vapor evolution. In reality, vapor formation occurs at the leak point due to flashing, aerosolization and atmospheric heat transfer. To assess this portion of the vapor dispersion, Phast scenarios of the spill cases were modeled.

To assess the formation and dispersion of vapor due to flashing and similar effects at the leak point, two Phast cases were used in tandem. The first case modeled a two phase release from a point source at design spill conditions. This case was used to determine the fraction of liquid rain out, and conversely the rate of vapor release. This vapor-only release rate was then modeled in a second Phast scenario to gauge the flammable vapor cloud formation.

Summary plots of each case are included in Appendix K. The calculations show that none of the flammable vapor cloud exclusion zones extend beyond the property line that can be built upon.

9.0 VAPOR CLOUD EXPLOSION

The following sections outline the criteria for assessing Vapor Cloud Explosion (VCE) from the credible spill scenarios described above, a description of the analysis conducted, and an assessment of the results.

9.1 Requirements

Per the PHMSA LNG Facility Siting FAQ, Vapor Cloud Explosion (VCE) analysis should be included in an LNG plant's hazard evaluation if the hazard is present. Correspondence with PHMSA has indicated that a 1 psi overpressure threshold should be evaluated at the property line that can be built upon and at any occupied buildings in the facility.

9.2 Scenario Assessment for VCE

Due to the open site plan and the low reactivity of natural gas (methane), scenarios involving natural gas were not deemed credible for VCE. Medium and high reactivity substances, such as MR and its constituents, have a higher propensity to generate explosive overpressure and were evaluated. VCE scenario plots, fuel reactivity & flammable mass calculations, Phast analysis plots are contained in Appendix L.

The plot plan was assessed for areas of congestion and confinement within the flammable vapor cloud of the credible MR release scenarios, with a particular focus on scenarios in proximity to the control building (MRL Condenser Vessel V-204 failure). Two areas were identified that may have the potential to hold up flammable vapor:

- Area 1 Liquefaction Area
- Area 2 Adjacent to Compressor Building

For each case, the plan area of the VCE zone and flammable cloud height were used to determine a maximum hold up volume. A stoichiometric combustion ratio was calculated for the MR vapor and was applied to the volume to determine the mass of flammable fuel to include in the VCE model.

The MR vapor composition was also used to determine a composite laminar flame speed and thereby classify the fuel reactivity as Medium.

Factors for congestion and confinement were identified based on qualitative assessment of the current facility layout and were assigned to each area.

Using the inputs described above, a Baker-Strehlow-Tang explosion model was run using Phast version 7.01. Results show that the 1.0 psi blast overpressure isopleth remains within the property line that can be built upon and does not encroach on occupied buildings in the facility (the control room). Overpressure isopleth plots are included in Appendix L.

10.0 CONCLUSIONS

Analysis has been performed to determine safe plant layout and siting requirements for the Tacoma LNG Facility, including spill impoundment sizing, fire thermal radiation flux modeling, flammable vapor dispersion modeling and flammable Vapor Cloud Explosion (VCE) modeling.

Credible design spill scenarios were identified using the PHMSA line assessment procedure and failure rate criteria. These credible scenarios were used to size spill conveyances and impoundments, perform fire thermal radiation modeling and vapor dispersion analysis.

Spill impoundment is required for design spills from the liquefaction, ship bunkering and truck loading LNG lines. The process spill sump, TOTE transition pit sumps, and the future Hylebos sump are adequately sized to hold design spills and meet all regulatory requirements.

Fire thermal radiation modeling has been completed for all spill sumps. Results show that thermal radiation flux exclusion zones specified by regulation do not extend beyond the property line that can be built upon (public right of way adjacent to the facility).

Vapor dispersion analysis was conducted for all credible design spill scenarios. Vapor and non-cryogenic liquid releases were analyzed using Phast consequence modeling software. Results show that the ½ LFL vapor exclusion zones do not extend beyond the property line that can be built upon (public right of way adjacent to the facility). Additional passive measures, in the form of vapor fencing, were implemented in the southern section of the facility to ensure no vapor cloud encroachment onto 11th St.

Cryogenic liquid releases (LNG) were analyzed using FLACS 3D computation fluid dynamics modeling software, performed by Gexcon. The FLACS analysis shows that the ½ LFL vapor exclusion zones do not extend beyond the property line that can be built upon (public right of way adjacent to the facility). Subsequent modifications to the site layout will not impact this final conclusion. Additional passive measures, in the form of vapor fencing, will be implemented near the TOTE loading dock impoundment to minimize vapor cloud encroachment into the TOTE marshalling area. Supporting Phast analysis also showed that flash vapor generated at the release point did not extend the exclusion zones beyond the property boundaries or property that cannot be built upon (public right of way adjacent to the facility).

Vapor Cloud Explosion (VCE) analysis was conducted for the design spill scenarios involving MR. Phast analysis shows that the 1.0 psi overpressure isopleths do not extend beyond the property line that can be built upon and do not encroach on occupied buildings in the facility (the Control/Admin building).

APPENDIX A – PIPE INVENTORY & FAILURE RATE CALCULATIONS

Pipe Inventory & Failure Rate Calculations - Hole Size Evaluation

Revision:	A	Job Number:	186512
Date:	27-Mar-2015	Document No.	186512-000-PR-LS-01000
Made By:	LA	Calculation No.	
Checked:	GCB	Client:	Puget Sound Energy
Office:	PSE	Project:	Tacoma LNG

Item #	Pipe Segment	Line #	Fluid Code	Plot Plan DWG No.	Origin		Destination		HMB Case & Stream #		Stream Conditions				Line Size (in)	Estimated Line Length		Line Volume (ft³)	FERC Failure Rate Per Year of Operation w.r.t Type of Failure				CHECK for Hole Size > 3E-5	Hole Size Analyzed (in)	Analysis By	Comments
					From	P&ID #	To	P&ID #	Case	Stream #	Vapor Frac.	Temperature (deg °F)	Pressure (psia)	Flow Rate (lb/hr)		(ft)	(m)		Piping (P1): Catastrophic Rupture	Piping (P2): Release from hole w/ Effective diameter of 1/3 Diameter	Piping (P3): Release from hole w/ Effective diameter of 10% Diameter, up to 2"	Piping (P4): Release from hole w/ Effective diameter of 1"				
1	12"-NG-1001-01CB1S01-N-	1001	NG	000-PI-01-000001	Meter Station	186512-000-PR-03-010001	12x8 Reducer	010001	Design	1	1.000	70.0	184.7	44,126	12	20	6.098	15.7	4.27E-07	1.22E-06	2.44E-06	3.05E-06	-	-	-	-
2	8"-NG-1001-01CB1S01-N-	1001	NG	000-PI-01-000001	12x8 Reducer	186512-000-PR-03-010001	F-101	010001	Design	1	1.000	70.0	184.7	44,126	8	20	6.098	7.0	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	-
3	8"-NG-1002-01CB1S01-N-	1002	NG	000-PI-01-000001	F-101	186512-000-PR-03-010001	C-101	010101	Design	2	1.000	69.4	174.7	44,126	8	290	88.41	101.2	1.77E-05	3.54E-05	N/A	6.19E-05	P2	2.67	Phast	-
4	2"-NG-1002-01CB1S01-N-	1002	NG	000-PI-01-000001	Line 8"-1002	186512-000-PR-03-010001	Line 2" to FG	010001	Off-Design	N/A	1.000	69.4	174.7	TBD	2	220	67.07	4.8	3.35E-05	N/A	N/A	1.34E-04	P1	2.00	Assoc. to #3	-
5	4"-NG-3010-03CB1S01-N-	3010	NG	000-PI-01-000001	Line 3"-3010	186512-000-PR-03-010001	Meter Station	010001	Off-Design	24	1.000	110.5	474.7	4,323	4	50	15.24	4.4	7.62E-06	N/A	N/A	3.05E-05	P4	1.00	Assoc. to #81	-
8	2"-NG--03CB1S01-N-	X24	NG	000-PI-01-000001	Line 10"-NG	186512-000-PR-03-010001	F-801	080101	Design	74	1.000	64.6	263.7	2,632	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
9	8"-NG-1004-01CB1S01-N-	1004	NG	000-PI-01-000001	Line 8"-1002	186512-000-PR-03-010101	Line 8"-1006	010102	Off-Design	N/A	1.000	69.4	174.7	NNF	8	50	15.24	17.5	3.05E-06	6.10E-06	N/A	1.07E-05	-	-	-	NNF
10	6"-NG-1005-03CB1S01-PP-1.0	1005	NG	000-PI-01-000001	C-101	186512-000-PR-03-010101	EC-101	010102	Design	3	1.000	258.9	539.7	44,126	6	80	24.39	15.7	4.88E-06	9.76E-06	N/A	1.71E-05	-	-	-	-
12	6"-NG-1009-01CB1S01-N-	1009	NG	000-PI-01-000001	FV / EC-101	186512-000-PR-03-010101	8"-1002 / C-101	010101	Off-Design	N/A	1.000	94.2	524.7	NNF	6	20	6.098	3.9	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	NNF
14	8"-NG-1006-03CB1S01-N-	1006	NG	000-PI-01-000001	8x6 / EC-101	186512-000-PR-03-010102	Pretreatment	012001	Design	4	1.000	94.2	524.7	44,126	8	140	42.68	48.9	8.54E-06	1.71E-05	N/A	2.99E-05	-	-	-	-
15	6"-NG-1006-03CB1S01-N-	1006	NG	000-PI-01-000001	EC-101	186512-000-PR-03-010102	8x6 Pretreatment	010102	Design	4	1.000	94.2	524.7	44,126	6	20	6.098	3.9	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	-
16	6"-NG-1007-03CB1S01-N-	1007	NG	000-PI-01-000001	EC-101	186512-000-PR-03-010102	FV / C-101	010101	Off-Design	N/A	1.000	94.2	524.7	NNF	6	100	30.49	19.6	6.10E-06	1.22E-05	N/A	2.13E-05	-	-	-	NNF
18	6"-NG-1010-03CB1S01-N-	1010	NG	000-PI-01-000001	Pretreatment	186512-000-PR-03-012001	E-201	020001	Design	6	1.000	111.3	484.7	41,876	6	480	146.3	94.2	2.93E-05	5.85E-05	N/A	1.02E-04	P2	2.00	Phast	-
19	2"-NG-1011-03CB1S01-N-	1011	NG	000-PI-01-000001	6"-1010	186512-000-PR-03-012001	C-101 Startup	012001	Off-Design	N/A	1.000	111.3	484.7	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
20	2"-NG-1012-01CB1S01-N-	1012	NG	000-PI-01-000001	HV-Pretreatment	186512-000-PR-03-012001	8"-1002 / C-101	010101	Off-Design	N/A	1.000	111.3	484.7	NNF	2	35	10.67	0.8	5.34E-06	N/A	N/A	2.13E-05	-	-	-	NNF
21	2"-FG--01CB1S01-ET-1.0	X25	FG	000-PI-01-000001	Pretreatment	186512-000-PR-03-012001	U-910	012001	Off-Design	N/A	0.000	100.0	70.0	TBD	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
22	6"-LNG-2002-03SA0S30-CC-3.0	2002	LNG	000-PI-01-000001	E-201	186512-000-PR-03-020001	V-201	020001	Design	7	0.995	-90.0	479.7	41,876	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
23	6"-LNG-2003-03SA0S30-CC-3.0	2003	LNG	000-PI-01-000001	V-201	186512-000-PR-03-020001	E-201	020001	Design	8	1.000	-90.0	479.7	41,414	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
24	6"-NG-2004-03SA0S30-N-	2004	NG	000-PI-01-000001	E-201	186512-000-PR-03-020001	E-202	020001	Design	9 / 10	1.000	95.5	474.7	45,736	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
25	3"-LNG-2005-03SA0S30-CC-4.5	2005	LNG	000-PI-01-000001	E-202	186512-000-PR-03-020001	FV / E-202	020001	Design	11	0.000	-255.0	469.7	45,736	3	330	100.6	16.2	5.03E-05	N/A	N/A	2.01E-04	P1	3.00	FLACS	-
26	6"-LNG-2006-01SA0S30-CC-4.5	2006	LNG	000-PI-01-000001	FV / E-202	186512-000-PR-03-020001	TK-401	040001	Design	12	0.000	-253.1	33.7	45,736	6	140	42.68	27.5	8.54E-06	1.71E-05	N/A	2.99E-05	-	-	-	-
27	2"-LNG-2007-03SA0S30-CC-3.0	2007	LNG	000-PI-01-000001	V-201	186512-000-PR-03-020001	FV / V-201	020001	Design	30	0.000	-90.0	479.7	463	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
28	2"-LNG-2008-03SA0S30-CC-3.0	2008	LNG	000-PI-01-000001	FV / V-201	186512-000-PR-03-020001	E-201	020001	Design	31	0.331	-130.0	123.8	463	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
29	2"-NG-2009-03CB1S01-N-	2009	NG	000-PI-01-000001	E-201	186512-000-PR-03-020001	V-801	080101	Design	32	0.859	94.2	118.8	463	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
30	10"-MR-2016-03SA0S30-CC-3.0	2016	MR	000-PI-01-000001	E-202	186512-000-PR-03-020001	E-202	020001	Design	N/A	1.000	-52.0	570.0	204,694	10	20	6.098	10.9	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	
31	6"-MR-2017-03SA0S30-CC-4.5	2017	MR	000-PI-01-000001	E-202	186512-000-PR-03-020001	PV / E-202	020001	Design	46	0.000	-255.0	565.0	202,805	6	20	6.098	3.9	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	-
32	8"-MR-2018-03SA0S30-CC-5.0	2018	MR	000-PI-01-000001	PV / E-202	186512-000-PR-03-020001	E-202	020001	Design	47	0.053	-259.0	87.0	202,805	8	20	6.098	7.0	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	-
33	20"-MR-2019-03CB1S01-N-	2019	MR	000-PI-01-000001	E-202	186512-000-PR-03-020001	V-202	020201	Design	40	1.000	89.2	77.0	305,304	20	230	70.12	501.8	1.40E-06	7.01E-06	1.40E-05	2.80E-05	-	-	-	-
34	8"-MR-2021-03SA0S30-CC-5.0	2021	MR	000-PI-01-000001	E-202	186512-000-PR-03-020001	TV / E-202	020001	Design	50	0.000	-6.0	560.2	100,610	8	20	6.098	7.0	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	-
35	8"-MR-2021-03SA0S30-CC-5.0	2021	MR	000-PI-01-000001	TV / E-202	186512-000-PR-03-020001	V-209	020001	Design	51	0.186	-30.1	82.0	100,610	8	40	12.2	14.0	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
36	6"-MR-2022-03SA0S30-CC-5.0	2022	MR	000-PI-01-000001	V-209	186512-000-PR-03-020001	E-202	020001	Design	51 vapor	1.000	-30.1	82.0	18,713	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
37	4"-MR-2023-03SA0S30-CC-3.0	2023	MR	000-PI-01-000001	V-209	186512-000-PR-03-020001	E-202	020001	Design	51 liquid	0.000	-30.1	82.0	81,897	4	40	12.2	3.5	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
38	10"-MR-2026-03SA0S30-CC-3.0	2026	MR	000-PI-01-000001	10"-2016	186512-000-PR-03-020001	FV / E-201	020001	Design	52	0.000	-52.0	570.0	1,888	10	10	3.049	5.5	6.10E-07	1.22E-06	N/A	2.13E-06	-	-	-	-
39	2"-MR-2027-03SA0S30-CC-3.0	2027	MR	000-PI-01-000001	FV / E-201	186512-000-PR-03-020001	E-201	020001	Design	53	0.334	-109.9	82.0	1,888	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
40	3"-MR-2028-03CB1S01-N-	2028	MR	000-PI-01-000001	E-201	186512-000-PR-03-020001	20"-2019	020001	Design	54	1.000	94.2	77.0	1,888	3	40	12.2	2.0	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
41	10"-MR-2015-03CB1S01-N-	2015	MR	000-PI-01-000001	V-204	186512-000-PR-03-020101	E-202	020001	Design	45	1.000	94.2	575.0	204,694	10	40	12.2	21.8	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	distance from separator to platefin to be minimized
42	4"-MR-2020-03CB1S01-N-	2020	MR	000-PI-01-000001	V-204	186512-000-PR-03-020101	E-202	020001	Design	49	0.008	93.5	563.2	100,610	4	45	13.72	3.9	6.86E-06	N/A	N/A	2.74E-05	-	-	-	distance from separator to platefin to be minimized
43	16"-MR-2037-03CB1S01-N-	2037	MR	000-PI-01-000001	EC-204	186512-000-PR-03-020101	V-204	020101	Design	44	0.787	94.2	580.0	305,304	16	40	12.2	55.9	8.54E-07	2.44E-06	4.88E-06	6.10E-06	-	-	-	-
44	10"-MR-2038-03CB1S01-N-	2038	MR	000-PI-01-000001	10"-2015	186512-000-PR-03-020101	PV / V-202	020201	Off-Design	N/A	1.000	94.2	575.0	NNF	10	50	15.24	27.3	3.05E-06	6.10E-06	N/A	1.07E-05	-	-	-	NNF
46	2"-MR-2040-03CB1S01-N-	2040	MR	000-PI-01-000001	10"-2015	186512-000-PR-03-020101	PV / V-205	021001	Off-Design	N/A	1.000	94.2	575.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
47	20"-MR-2032-03CB1S01-N-	2032	MR	000-PI-01-000001	V-202	186512-000-PR-03-020201	C-201	020301	Design	40	1.000	89.2	77.0	305,304	20	20	6.098	43.6	1.22E-07	6.10E-07	1.22E-06	2.44E-06	-	-	-	-
48	2"-MR-2033-03CB1S01-N-	X2 (2033 Duplicate)	MR	000-PI-01-000001	V-202	186512-000-PR-03-020201	2"-2102	020201	Off-Design	N/A	0.000	89.2	77.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
49	10"-MR-2044-03CB1S01-N-	2044	MR	000-PI-01-000001	PV / V-202	186512-000-PR-03-020201	20"-2019	020201	Off-Design	N/A	1.000	97.2	575.0	NNF	10	40	12.2	21.8	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	NNF
50	12"-MR-2033-06CB1S01-PP-1.0	2033	MR	000-PI-01-000001	C-201	186512-000-PR-03-020301	EC-204	020101	Design	43	1.000	277.0	592.0	305,304	12	50	15.24	39.3	1.07E-06	3.05E-06	6.10E-06	7.62E-06	-	-	-	-
51	6"-MR-2035-06CB1S01-N-	2035	MR	000-PI-01-000001	12"-2033	186512-000-PR-03-020301	HV / C-201	020301	Off-Design	N/A	1.000	277.0	592.0	75,000	6	50	15.24	9.8	3.05E-06	6.10E-06	N/A	1.07E-05	-	-	-	NNF
52	6"-MR-2041-03CB1S01-N-	2041	MR	000-PI-01-000001	HV / C-201	186512-000-PR-03-020301	20"-2032	020301	Off-Design	N/A	1.000	277.0	592.0	75,000	6	20	6.098	3.9	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	NNF
56	10"-MR-2043-03CB1S01-N-	2043	MR	000-PI-01-000001	C-201-V01	186512-000-PR-03-020302	PV / 10"-2044	020201	Off-Design	N/A	1.000	111.3	147.0	NNF	10	40	12.2	21.8	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	NNF
57	2"-MR-2042-03CB1S01-N-	2042	MR	000-PI-01-000001	C-201 1st Stage	186512-000-PR-03-020302	2"-X2	020201	Off-Design	N/A	1.000	120.4	37.4	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
58	2"-MR-2045-03CB1S01-N-	2045	MR	000-PI-01-000001	C-201-V01	186512-000-PR-03-020302	2"-2042	020201	Off-Design	N/A	0.000	111.3	147.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
59	2"-MR-2111-03CB1S01-N-	2111	MR	000-PI-01-000001	10"-2043	186512-000-PR-03-020302	PCV / V-206	021002	Off-Design	N/A	1.000	111.3	147.0	NNF	2	390	118.9	8.5	5.95E-05	N/A	N/A	2.38E-04	-	-	N/A	NNF
60	2"-MR-2101-03CB1S01-N-	2101	MR	000-PI-01-000001	V-205	186512-000-PR-03-021001	PV / V-205	021001	Off-Design	N/A	1.000	94.2	575.0	0	2	325	99.09	7.1	4.95E-05	N/A	N/A	1.98E-04	P1	2.00	Phast	
61	2"-MR-2102-03CB1S01-N-	2102	MR	000-PI-01-000001	PV / V-202	186512-000-PR-03-021001	2"-2033	020201	Off-Design	N/A	1.000	89.2	77.0	0	2	210	64.02	4.6	3.20E-05	N/A	N/A	1.28E-04	P1	2.00	Phast	
62	2"-MR-2106-03CB1S01-N-	2106	MR	000-PI-01-000001	V-205	186512-000-PR-03-021001	20"-2019	020201	Off-Design	N/A	1.000	94.2	575.0	NNF	2	390	118.9	8.5	5.95E-05	N/A	N/A	2.38E-04	-	-	N/A	NNF
63	2"-MR-2112-01CB1S01-N-	2112	MR	000-PI-01-000001	PCV / V-206	186512-000-PR-03-021002	V-206	021002	Off-Design	N/A	1.000	111.3	147.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
64	2"-MR-2113-01CB1S01-N-	2113	MR	000-PI-01-000001	2"-2112	186512-000-PR-03-021002	V-207	021002	Off-Design	N/A	1.000	111.3	147.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
65	2"-MR-2116-01CB1S01-N-	2116	MR	000-PI-01-000001	V-206	186512-000-PR-03-021002	V-206 Fill Hose	021002	Off-Design	N/A	0.000	13.0	50.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
66	2"-MR-2117-01CB1S01-N-	2117	MR	000-PI-01-000001	V-207	186512-000-PR-03-021002	V-207 Fill Hose	021002	Off-Design	N/A	0.000	70.0	50.0	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
67	2"-MR-2118-01CB1S01-N-	2118	MR	000-PI-01-000001	2"-2112	186512-000-PR-03-021002	2"-2119	021002	Off-Design	N/A	1.000	13.9	50.0	NNF	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
68	2"-MR-2119-01CB1S01-N-	2119	MR	000-PI-01-000001	2"-2118	186512-000-PR-03-021002	V-206 Vap Rtn	021002	Off-Design	N/A	1.000	13.9	50.0	NNF	2	30	9.146	0.7	4.57E-06	N/A	N/A	1.83E-05	-	-	-	NNF
69	2"-MR-2120-01CB1S01-N-	2120	MR	000-PI-01-000001	2"-2113	186512-000-PR-03-021002	2"-2120	021002	Off-Design	N/A	1.000	97.2	14.7	NNF	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
70	2"-MR-2121-01CB1S01-N-	2121	MR	000-PI-01-000001	2"-2120	186512-000-PR-03-021002	V-207 Vap Rtn	021002	Off-Design	N/A	1.000	97.2	14.7	NNF	2	30	9.146	0.7	4.57E-06	N/A	N/A	1.83E-05	-	-	-	NNF
71	6"-MR-2122-01CB1S01-N-	2122	MR	000-PI-01-000001	V-206	186512-000-PR-03-021002	Strainer	021002	Off-Design	N/A	0.000	70.0	50.0	NNF	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	NNF
72	2"-MR-2123-03CB1S01-N-	2123	MR	000-PI-01-000001	Strainer	186512-000-PR-03-021002	2"-2102	020201	Off-Design	N/A	0.000	70.0	50.0	NNF	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
73	2"-MR-2124-01CB1S01-N-	2124	MR	000-PI-01-000001	V-207	186512-000-PR-03-021002	6"-2122	021002	Off-Design	N/A	0.000	70.0	50.0	NNF	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
74	2"-ET-2131-03SA0S30-N-	2131	ET	000-PI-01-000001	2"-2132	186512-000-PR-03-021003	V-208 Fill Hose	021003	Off-Design	N/A	0.000	-20.0	293.0	NNF	2	30	9.146	0.7	4.57E-06	N/A	N/A	1.83E-05	-	-	-	NNF
75	2"-ET-2132-03CB1S01-N-	2132	ET	000-PI-01-000001	V-208	186512-000-PR-03-021003	2"-2131	021003	Off-Design	N/A	0.000	-20.0	293.0	NNF	2	10	3.049	0.2	1.52E-06	N/A	N/A	6.10E-06	-	-	-	NNF
76	2"-ET-2133-03CB1S01-N-	2133	ET	000-PI-01-000001	V-208	186512-000-PR-03-021003	2"-2134	021003	Off-Design	N/A	0.000	-20.0	293.0	NNF	2	10	3.049	0.2	1.52E-06	N/A	N/A	6.10E-06	-	-	-	NNF
77	2"-ET-2134-03SA0S30-N-	2134	ET	000-PI-01-000001	2"-2133	186512-000-PR-03-021003	PCV / V-208	021003	Off-Design	N/A	0.000	-20.0	293.0	NNF	2	30	9.146	0.7	4.57E-06	N/A	N/A	1.83E-05	-	-	-	NNF
78	8"-NG-3002-01CB1S01-N-	3002	NG	000-PI-01-000001	E-301	186512-000-PR-03-030001	V-301	030101	Design	22	1.000	-20.0	14.7	4,323	8	40	12.2	14.0	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
79	2"-NG-3008-03CB1S01-N-	3008	NG	000-PI-01-000001	3"-3003	186512-000-PR-03-030001	3"-8001	080101	Off-Design	23	1.000	110.5	474.7	389	2	260	79.27	5.7	3.96E-05	N/A	N/A	1.59E-04	P1	2.00	Phast	-
80	2"-NG-3009-03CB1S01-N-	3009	NG	000-PI-01-000001	3"-3003	186512-000-PR-03-030001	E-301	030001	Off-Design	N/A	1.000	110.5	474.7	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
81	3"-NG-3010-03CB1S01-N-	3010	NG	000-PI-01-000001	PV / C-301	186512-000-PR-03-030001	4"-3010	010001	Design	23	1.000	110.5	264.7	4,323	3	290	88.41	14.2	4.42E-05	N/A	N/A	1.77E-04	P1	3.00	Phast	-
82	3"-NG-3011-03CB1S01-N-	3011	NG	000-PI-01-000001	3"-3003	186512-000-PR-03-030001	3"-3012	030001	Design	23	1.000	110.5	474.7	4,323	3	40	12.2	2.0	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
83	3"-NG-3012-03CB1S01-N-	3012	NG	000-PI-01-000001	PV / C-301	186512-000-PR-03-030001	6"-2004	020001	Design	23	1.000	110.5	474.7	4,323	3	190	57.93	9.3	2.90E-05	N/A	N/A	1.16E-04	P4	1.00	Assoc. to #79	-
84	6"-LNG-4036-01SA0S30-CC-4.5	4036	LNG	000-PI-01-000001	HYLEBOS	186512-000-PR-03-040103	8"-3001	030001	Design	62	1.000	-240.0	15.2	3,593	6	1000	304.9	196.3	6.10E-05	1.22E-04	N/A	2.13E-04	P1	6.00	Phast	
85	6"-NG--01CB1S01-N-	X28	NG	000-PI-01-000001	V-301	186512-000-PR-03-030101	C-301A	030101	Design	22	1.000	-20.0	14.7	2,161	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
86	6"-NG--01CB1S01-N-	X29	NG	000-PI-01-000001	8"-X29	186512-000-PR-03-030101	C-301B	030201	Design	22	1.000	-20.0	14.7	2,161	6	60	18.29	11.8	3.66E-06	7.32E-06	N/A	1.28E-05	-	-	-	-
87	3"-NG--03CB1S01-N-	X3 / 3003	NG	000-PI-01-000001	V-302	186512-000-PR-03-030101	PV / C-301	030001	Design	23	1.000	110.5	474.7	4,323	3	40	12.2	2.0	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
88	3"-NG-3006-03CB1S01-N-	3006	NG	000-PI-01-000001	C-301B	186512-000-PR-03-030201	E-302	030101	Design	N/A	1.000	284.1	500.7	2,161	3	40	12.2	2.0	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
89	2"-FG-3501-01CB1S01-N-	3501	FG	000-PI-01-000001	2"-8005	186512-000-PR-03-035001	PCV / HS-351	035001	Design	N/A	1.000	114.9	69.7	TBD	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	assist gas
90	2"-FG-3502-01CB1S01-N-	3502	FG	000-PI-01-000001	PCV / HS-351	186512-000-PR-03-035001	2"-4084	035001	Design	N/A	1.000	114.9	69.7	TBD	2	30	9.146	0.7	4.57E-06	N/A	N/A	1.83E-05	-	-	-	assist gas
91	8"-LNG-3503-01SA0S30-N-	3503	LNG	000-PI-01-000001	V-351	186512-000-PR-03-035001	HS-351	035001	Design	N/A	1.000	-240.0	15.2	TBD	8	220	67.07	76.8	1.34E-05	2.68E-05	N/A	4.70E-05	P4	1.00	Assoc. to #84	gas to flare
92	8"-LNG-3504-01SA0S30-N-	3504	LNG	000-PI-01-000001	Flare Header	186512-000-PR-03-035001	8"-4084	035001	Design	N/A	1.000	-240.0	15.2	TBD	8	280	85.37	97.7	1.71E-05	3.41E-05	N/A	5.98E-05	P2	2.67	Assoc. to #84	seal gas leakage & chromatograph sweeps
94	8"-LNG-4084-01SA0S30-N-	4084	LNG	000-PI-01-000001	4"-4084	186512-000-PR-03-035001	V-351	035001	Design	N/A	1.000	114.9	69.7	TBD	8	640	195.1	223.4	3.90E-05	7.80E-05	N/A	1.37E-04	P1	8.00	N/A	process flare header - acid gas not flammable
95	8"-BOG-3001-01SA0S30-CC-5.0	3001	BOG	000-PI-01-000001	TK-401	186512-000-PR-03-040001	E-301	030001	Design	21	1.000	-240.0	15.2	4,323	8	630	192.1	219.9	3.84E-05	7.68E-05	N/A	1.34E-04	P1	8.00	Phast	-
96	6"-LNG--01SA0S30-CC-4.5	X35	LNG	000-PI-01-000001	6"-2006	186512-000-PR-03-040001	TK-401	040001	Design	12	0.000	-253.1	33.7	45,736	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	NNF
100	2"-LNG--01SA0S30-CC-4.0	X31	LNG	000-PI-01-000001	6"-2006	186512-000-PR-03-040001	TK-401	040001	Design	N/A	0.000	-253.1	33.7	NNF	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
101	6"-LNG-4001-01SA0S30-CC-4.5	4001	LNG	000-PI-01-000001	P-401A	186512-000-PR-03-040101	10"-4007	040101	Design	60	0.000	-258.6	158.5	288,068	6	30	9.146	5.9	1.83E-06	3.66E-06	N/A	6.40E-06	-	-	-	-
102	6"-LNG-4002-01SA0S30-CC-4.5	4002	LNG	000-PI-01-000001	6"-4001	186512-000-PR-03-040101	10"-4009	040101	Off-Design	N/A	0.000	-258.6	158.5	288,068	6	30	9.146	5.9	1.83E-06	3.66E-06	N/A	6.40E-06	-	-	-	-

Revision:	A
Date:	27-Mar-2015
Made By:	LA
Checked:	GCB
Office:	PSE

Pipe Inventory & Failure Rate Calculations - Hole Size Evaluation

Client: Puget Sound Energy
Project: Tacoma LNG

Job Number:	186512
Document No.	186512-000-PR-LS-01000
Calculation No.	

Item #	Pipe Segment	Line #	Fluid Code	Plot Plan DWG No.	Origin		Destination		HMB Case & Stream #		Stream Conditions				Line Size (in)	Estimated Line Length		Line Volume (ft^3)	FERC Failure Rate Per Year of Operation w.r.t Type of Failure				CHECK for Hole Size > 3E-5	Hole Size Analyzed (in)	Analysis By	Comments
					From	P&ID #	To	P&ID #	Case	Stream #	Vapor Frac.	Temperature (deg °F)	Pressure (psia)	Flow Rate (lb/hr)		(ft)	(m)		Piping (P1): Catastrophic Rupture	Piping (P2): Release from hole w/ Effective diameter of 1/3 Diameter	Piping (P3): Release from hole w/ Effective diameter of 10% Diameter, up to 2"	Piping (P4): Release from hole w/ Effective diameter of 1"				
103	6"-LNG-4003-01SA0S30-CC-4.5	4003	LNG	000-PI-01-000001	P-401B	186512-000-PR-03-040101	10"-4007	040101	Design	60	0.000	-258.6	158.5	288,068	6	30	9.146	5.9	1.83E-06	3.66E-06	N/A	6.40E-06	-	-	-	-
104	6"-LNG-4004-01SA0S30-CC-4.5	4004	LNG	000-PI-01-000001	6"-4003	186512-000-PR-03-040101	10"-4009	040101	Off-Design	N/A	0.000	-258.6	158.5	288,068	6	30	9.146	5.9	1.83E-06	3.66E-06	N/A	6.40E-06	-	-	-	-
105	6"-LNG-4005-01SA0S30-CC-4.5	4005	LNG	000-PI-01-000001	P-401C	186512-000-PR-03-040101	10"-4007	040101	Design	60	0.000	-258.6	158.5	288,068	6	30	9.146	5.9	1.83E-06	3.66E-06	N/A	6.40E-06	-	-	-	-
106	6"-LNG-4006-01SA0S30-CC-4.5	4006	LNG	000-PI-01-000001	6"-4005	186512-000-PR-03-040101	10"-4009	040101	Off-Design	N/A	0.000	-258.6	158.5	288,068	6	30	9.146	5.9	1.83E-06	3.66E-06	N/A	6.40E-06	-	-	-	-
107	10"-LNG-4007-01SA0S30-CC-5.0	4007	LNG	000-PI-01-000001	LNG Header	186512-000-PR-03-040101	LNG Distrib.	040102	Design	N/A	0.000	-258.6	158.5	1,071,500	10	410	125	223.6	2.50E-05	5.00E-05	N/A	8.75E-05	P2	3.33	FLACS	-
108	10"-LNG-4009-01SA0S30-CC-5.0	4009	LNG	000-PI-01-000001	Recycle Header	186512-000-PR-03-040101	TK-401	040101	Off-Design	N/A	0.000	-258.6	158.5	576,136	10	40	12.2	21.8	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
109	10"-LNG-4017-01SA0S30-CC-5.0	4017	LNG	000-PI-01-000001	10"-4007	186512-000-PR-03-040102	10"-4060	040301	Design	65	0.000	-258.6	158.5	1,071,500	10	350	106.7	190.9	2.13E-05	4.27E-05	N/A	7.47E-05	P2	3.33	FLACS	-
110	4"-LNG-4018-01SA0S30-CC-4.5	4018	LNG	000-PI-01-000001	10"-4017	186512-000-PR-03-040102	U-405	040401	Design	63	0.000	-258.1	50.0	130,637	4	150	45.73	13.1	2.29E-05	N/A	N/A	9.15E-05	P4	1.00	FLACS	-
111	2"-LNG-4021-01SA0S30-N-	4021	LNG	000-PI-01-000001	E-306	186512-000-PR-03-040102	8"-3001	030001	Off-Design	N/A	1.000	-88.3	15.7	1,136	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
112	6"-LNG-4022-01SA0S30-CC-4.5	4022	LNG	000-PI-01-000001	10"-4007	186512-000-PR-03-040102	P-402	040201	Design	70	0.000	-258.5	151.0	119,745	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
113	8"-LNG-4023-01SA0S30-CC-5.0	4023	LNG	000-PI-01-000001	10"-4007	186512-000-PR-03-040102	HYLEBOS	040103	Design	61	0.000	-259.2	52.6	1,071,500	8	890	271.3	310.7	5.43E-05	1.09E-04	N/A	1.90E-04	P1	8.00	FLACS	Full Line Break at Run-out Flow of All Three Pumps
115	2"-LNG-4024-01SA0S30-CC-4.0	4024	LNG	000-PI-01-000001	HYLEBOS	186512-000-PR-03-040103	4x2 Exp	040102	Off-Design	N/A	1.000	-203.4	17.2	21,800	2	890	271.3	19.4	1.36E-04	N/A	N/A	5.43E-04	P1	2.00	Assoc. to #113	-
115	2"-LNG-4030-01SA0S30-CC-4.0	4030	LNG	000-PI-01-000001	8"-4023	186512-000-PR-03-040103	FV / HYLEBOS	040103	Off-Design	N/A	1.000	-203.4	17.2	TBD	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
115	8"-LNG-4031-01SA0S30-CC-5.0	4031	LNG	000-PI-01-000001	8"-4023	186512-000-PR-03-040103	8"-4036	040103	Off-Design	N/A	1.000	-203.4	17.2	NNF	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
116	4"-LNG-4026-01SA0S30-CC-4.5	4026	LNG	000-PI-01-000001	PV / LNG Distrib.	186512-000-PR-03-040102	10"-4009	040101	Off-Design	N/A	1.000	-258.8	17.2	7,000	4	40	12.2	3.5	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
120	6"-LNG-4037-01SA0S30-CC-4.5	4037	LNG	000-PI-01-000001	6"-4022	186512-000-PR-03-040201	P-402	040201	Design	70	0.000	-258.5	151.0	119,745	6	20	6.098	3.9	1.22E-06	2.44E-06	N/A	4.27E-06	-	-	-	-
121	6"-LNG-4038-03SA0S30-CC-4.5	4038	LNG	000-PI-01-000001	6x4 Exp	186512-000-PR-03-040201	Vap. Feed	040202	Design	71	0.000	-259.7	316.7	119,745	6	40	12.2	7.9	2.44E-06	4.88E-06	N/A	8.54E-06	-	-	-	-
122	4"-LNG-4038-03SA0S30-CC-4.5	4038	LNG	000-PI-01-000001	P-402	186512-000-PR-03-040201	6x4 Exp	040201	Design	71	0.000	-259.7	316.7	119,745	4	20	6.098	1.7	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
123	2"-LNG-4041-01SA0S30-CC-3.5	4041	LNG	000-PI-01-000001	P-402	186512-000-PR-03-040201	6"-X36	040201	Off-Design	N/A	1.000	-131.5	17.2	TBD	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	NNF
124	3"-LNG-4047-03SA0S30-CC-4.0	4047	LNG	000-PI-01-000001	6"-4038	186512-000-PR-03-040201	FV / LNG Vap	040201	Off-Design	N/A	0.000	-259.7	316.7	60,000	3	20	6.098	1.0	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
125	3"-LNG--01SA0S30-CC-4.0	X38	LNG	000-PI-01-000001	FV / LNG Vap	186512-000-PR-03-040201	4"-X37	040201	Off-Design	N/A	0.000	-258.5	151.0	60,000	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
127	4"-LNG--01SA0S30-CC-4.5	X37	LNG	000-PI-01-000001	Recycle Header	186512-000-PR-03-040201	10"-4009	040101	Off-Design	N/A	0.000	-259.7	316.7	NNF	4	190	57.93	16.6	2.90E-05	N/A	N/A	1.16E-04	-	-	N/A	NNF
128	2"-LNG-4054-01SA0S30-CC-3.0	4054	LNG	000-PI-01-000001	6"-4038	186512-000-PR-03-040202	4"-X37	040201	Off-Design	N/A	0.000	-257.9	316.7	25,000	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
129	6"-LNG-4055-03SA0S30-CC-4.5	4055	LNG	000-PI-01-000001	6"-4038	186512-000-PR-03-040202	FV / LNG Vap	040202	Design	71	0.000	-257.9	316.7	119,745	6	140	42.68	27.5	8.54E-06	1.71E-05	N/A	2.99E-05	-	-	-	-
130	6"-LNG-4056-03SA0S30-CC-4.5	4056	LNG	000-PI-01-000001	FV / LNG Vap	186512-000-PR-03-040202	E-402	040203	Design	71	0.000	-257.9	316.7	119,745	6	50	15.24	9.8	3.05E-06	6.10E-06	N/A	1.07E-05	-	-	-	-
131	10"-NG--03CB1S01-N-	X7	NG	000-PI-01-000001	10"-X8	186512-000-PR-03-040202	Plant Outlet	010001	Design	73	1.000	64.6	263.7	117,114	10	560	170.7	305.4	3.41E-05	6.83E-05	N/A	1.20E-04	P1	10.00	Phast	-
133	10"-LNG-4059-03SA0S30-N-	4059	LNG	000-PI-01-000001	E-402	186512-000-PR-03-040203	10"-X7	040202	Design	73	1.000	64.6	263.7	117,114	10	60	18.29	32.7	3.66E-06	7.32E-06	N/A	1.28E-05	-	-	-	-
137	10"-LNG-4062-01SA0S30-CC-5.0	4062	LNG	000-PI-01-000001	10"-4060	186512-000-PR-03-040301	Q-402	040302	Design	65	0.000	-258.1	80.1	1,071,500	10	330	100.6	180.0	2.01E-05	4.02E-05	N/A	7.04E-05	P2	3.33	FLACS	Run-out Flow of All Three Pumps
138	2"-LNG-4063-01SA0S30-CC-4.0	4063	LNG	000-PI-01-000002	10"-4062	186512-000-PR-03-040301	2"-4064	040301	Off-Design	N/A	1.000	-107.2	85.1	TBD	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
140	2"-LNG-4066-01SA0S30-CC-4.0	4066	LNG	000-PI-01-000001	2"-4065	186512-000-PR-03-040301	4"-4024	040102	Off-Design	N/A	1.000	-107.2	85.1	150	2	350	106.7	7.6	5.34E-05	N/A	N/A	2.13E-04	P1	2.00	Assoc. to #109	-
144	3"-LNG--01SA0S30-N-	X10	LNG	000-PI-01-000001	3"-X9	186512-000-PR-03-040301	8"-3001	030001	Off-Design	N/A	1.000	-107.2	85.1	NNF	3	380	115.9	18.7	5.79E-05	N/A	N/A	2.32E-04	-	-	N/A	NNF
145	3"-LNG--01SA0S30-N-	X11	LNG	000-PI-01-000001	3"-X10	186512-000-PR-03-040301	8"-4084	035001	Off-Design	N/A	1.000	-107.2	85.1	NNF	3	150	45.73	7.4	2.29E-05	N/A	N/A	9.15E-05	-	-	N/A	NNF
148	3"-LNG--01SA0S30-CC-4.0	X13	LNG	000-PI-01-000002	2"-X14	186512-000-PR-03-040302	3"-X9	040301	Off-Design	N/A	1.000	-108.2	80.1	NNF	3	330	100.6	16.2	5.03E-05	N/A	N/A	2.01E-04	-	-	Phast	NNF
149	2"-LNG--01SA0S30-CC-4.0	4064	LNG	000-PI-01-000002	8"-4062	186512-000-PR-03-040302	2"-4065	040301	Off-Design	N/A	1.000	-108.2	80.1	150	2	330	100.6	7.2	5.03E-05	N/A	N/A	2.01E-04	P1	2.00	Assoc. to #137	-
150	2"-LNG--01SA0S30-CC-4.0	X14	LNG	000-PI-01-000002	Q-402	186512-000-PR-03-040302	3"-X13	040302	Off-Design	N/A	1.000	-108.2	80.1	TBD	2	10	3.049	0.2	1.52E-06	N/A	N/A	6.10E-06	-	-	-	NNF
151	2"-LNG--01SA0S30-CC-4.0	X15	LNG	000-PI-01-000002	8"-4062	186512-000-PR-03-040302	2"-X14	040302	Off-Design		1.000	-108.2	80.1	TBD	2	10	3.049	0.2	1.52E-06	N/A	N/A	6.10E-06	-	-	-	NNF
152	2"-LNG--01SA0S30-CC-4.0	X16	LNG	000-PI-01-000002	8"-4062	186512-000-PR-03-040302	FV / TOTE	040302	Off-Design		0.000	-258.1	80.1	TBD	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
153	2"-LNG--01SA0S30-CC-4.0	X17	LNG	000-PI-01-000002	2"-X14	186512-000-PR-03-040302	2"-X14	040302	Off-Design		1.000	-108.2	80.1	TBD	2	10	3.049	0.2	1.52E-06	N/A	N/A	6.10E-06	-	-	-	NNF
154	3"-LNG-4073-01SA0S30-CC-4.0	4073	LNG	000-PI-01-000001	4"-4018	186512-000-PR-03-040401	Bay #1 Liq. Fill	040401	Design	64	0.000	-258.1	50.0	65,319	3	20	6.098	1.0	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
155	2"-LNG-4080-01SA0S30-N-	4080	LNG	000-PI-01-000001	Bay #2 Vap Rtn	186512-000-PR-03-040401	14"-4089	040401	Design	N/A	1.000	-258.2	17.7	NNF	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	NNF
157	3"-LNG-4085-01SA0S30-N-	4085	LNG	000-PI-01-000001	2"-4085	186512-000-PR-03-040401	3"-X10	030001	Off-Design	N/A	1.000	-258.2	17.7	NNF	3	150	45.73	7.4	2.29E-05	N/A	N/A	9.15E-05	-	-	N/A	NNF
158	3"-LNG-4088-01SA0S30-CC-4.0	4088	LNG	000-PI-01-000001	4"-4018	186512-000-PR-03-040401	Bay #2 Liq. Fill	040401	Design	64	0.000	-258.1	50.0	65,319	3	20	6.098	1.0	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
160	2"-LNG--01SA0S30-N-	X18	LNG	000-PI-01-000001	Bay #1 Vap Rtn	186512-000-PR-03-040401	2"-4080	040401	Design	N/A	1.000	-258.2	17.7	NNF	2	10	3.049	0.2	1.52E-06	N/A	N/A	6.10E-06	-	-	-	NNF
161	3"-NG-8001-03CB1S01-N-	8001	NG	000-PI-01-000001	V-801	186512-000-PR-03-080101	PV / V-801	080101	Design	N/A	1.000	120.0	116.8	389	3	40	12.2	2.0	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
162	3"-FG-8002-01CB1S01-N-	8002	FG	000-PI-01-000001	PV / V-801	186512-000-PR-03-080101	FG Header	080101	Design	34	1.000	114.9	69.7	389	3	160	48.78	7.9	2.44E-05	N/A	N/A	9.76E-05	P4	1.00	Assoc. to #165	-
163	3"-FG-8003-01CB1S01-N-	8003	FG	000-PI-01-000001	3"-8002	186512-000-PR-03-080101	PV / TK-401	040001	Off-Design	N/A	1.000	114.9	69.7	TBD	3	40	12.2	2.0	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
164	2"-FG-8005-01CB1S01-N-	8005	FG	000-PI-01-000001	3"-8002	186512-000-PR-03-080101	HS-351	035001	Design	N/A	1.000	114.9	69.7	TBD	2	180	54.88	3.9	2.74E-05	N/A	N/A	1.10E-04	P4	1.00	Assoc. to #165	-
165	2"-FG-8007-01CB1S01-N-	8007	FG	000-PI-01-000001	3"-8002	186512-000-PR-03-080101	Pretreatment	012001	Design	N/A	1.000	114.9	69.7	TBD	2	320	97.56	7.0	4.88E-05	N/A	N/A	1.95E-04	P1	2.00	Phast	-
166	2"-HL-8008-01CB1S01-N-	8008	HL	000-PI-01-000001	V-801	186512-000-PR-03-080101	2"-X21	080201	Design	N/A	0.000	120.0	34.7	62	2	270	82.32	5.9	4.12E-05	N/A	N/A	1.65E-04	P1	2.00	Phast	-
167	3"-FG-8011-01CB1S01-N-	8011	FG	000-PI-01-000001	3"-8002	186512-000-PR-03-080101	SG / V-801	080101	Off-Design	N/A	0.000	114.9	69.7	TBD	3	20	6.098	1.0	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
168	4"-FG--01CB1S01-N-	X19	FG	000-PI-01-000001	3"-8002	186512-000-PR-03-080101	E-402	040203	Design	N/A	1.000	114.9	69.7	TBD	4	40	12.2	3.5	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
169	2"-FG--01CB1S01-N-	X20	FG	000-PI-01-000001	3"-8002	186512-000-PR-03-080101	HS-951	035101	Design	N/A	1.000	114.9	69.7	TBD	2	50	15.24	1.1	7.62E-06	N/A	N/A	3.05E-05	P4	1.00	Assoc. to #165	-
171	2"-HL--01CB1S01-N-	X21	HL	000-PI-01-000001	2"-X23	186512-000-PR-03-080201	V-802	080201	Design	33	0.000	75.6	15.7	62	2	20	6.098	0.4	3.05E-06	N/A	N/A	1.22E-05	-	-	-	-
172	2"-HL--01CB1S01-N-	X22	HL	000-PI-01-000001	V-802	186512-000-PR-03-080201	P-802	080201	Design	N/A	0.000	75.6	16.7	8,122	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-
173	2"-HL--01CB1S01-N-	X23	HL	000-PI-01-000001	P-802	186512-000-PR-03-080201	Truck Conn.	080201	Design	N/A	0.000	76.0	43.8	8,122	2	40	12.2	0.9	6.10E-06	N/A	N/A	2.44E-05	-	-	-	-

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION - DO NOT RELEASE

Note:
1. Stream conditions and compositions based on design case. Refer to H&M Balance, 186512-PR-01-000101/104, Rev B.
2. Stream conditions not present in the H&M Balance are obtained from the Design or an appropriate Off-Design simulation model as required.
3. All distances are estimates based on available Plot Plan.
4. Final hole size selection based on maximum of the hole size determined by failure rate criteria and the largest connection to the pipe.
5. NNF (Normally No Flow) lines are not considered in credible failure scenarios due to infrequent operational utilization.
6. Pipeway elevations estimated to be 1.5 ft above grade.

APPENDIX B – PIPE FAILURE SCENARIO SUMMARY

Revision:	A	**Job Number:**	186512
Date:	6-May-2015	**Document No.**	186512-000-PR-LS-01000
Made By:	JG	**Calculation No.**	
Checked:	GCB	**Sheet**	
Office:	PSE		

Pipe Failure Scenario Summary

Client: Puget Sound Energy

Project: Tacoma LNG

Item #	Line Size (in)	Fluid Code	Line #	Line Description	Failure Case			Estimated Line Length	Consequence Analysis Tool	H&MB Reference		Leak Conditions			Calculated Leak Rate	Comments
					Code	Type	Hole Size (in)	(ft)		Case	Stream #	Vapor Frac.	Temp (°F)	Pressure (psia)	(lb/hr)	
3	8	NG	1002	plant inlet to pre-treatment	P2	1/3 Diameter Hole	2.67	290	Phast	Design	2	1.000	69.4	174.7	52,683	leak rate determined by Phast
18	6	NG	1010	pre-treatment to liquefier	P2	1/3 Diameter Hole	2.00	480	Phast	Design	6	1.000	111.3	484.7	80,677	leak rate determined by Phast
25	3	LNG	2005	rundown from liquefier to tank	P1	Catastrophic Rupture	3.00	330	FLACS	Design	11	0.000	-255.0	18.8	49,988	leak rate set to liquefaction rate plus 10%
60	2	MR	2101	MR equalization line	P1	Catastrophic Rupture	2.00	325	Phast	Off-Design	45	1.000	94.2	575.0	149,704	leak rate determined by Phast
61	2	MR	2102	MR equalization line	P1	Catastrophic Rupture	2.00	310	Phast	Off-Design	40	1.000	89.2	77.0	17,100	leak rate determined by Phast
79	2	NG	3008	BOG to fuel gas	P1	Catastrophic Rupture	2.00	260	Phast	Off-Design	23	1.000	110.5	474.7	82,873	leak rate determined by Phast
81	3	NG	3010	BOG to pipeline	P1	Catastrophic Rupture	3.00	290	Phast	Design	23	1.000	110.5	264.7	102,653	leak rate determined by Phast
84	6	LNG	4036	Hylebos ship vapor return	P1	Catastrophic Rupture	6.00	1000	Phast	Design	62	1.000	-240.0	15.2	9,866	leak rate determined by Phast
95	8	BOG	3001	BOG header	P1	Catastrophic Rupture	8.00	630	Phast	Design	21	1.000	-240.0	15.2	17,720	leak rate determined by Phast
107	10	LNG	4007	sendout header from tank	P2	1/3 Diameter Hole	3.33	410	FLACS	Design	N/A	0.000	-258.6	118.5	665,710	leak rate determined by Phast for input to FLACS model
109	10	LNG	4017	sendout to TOTE - facility side	P2	1/3 Diameter Hole	3.33	350	FLACS	Design	65	0.000	-258.6	114.5	652,757	leak rate determined by Phast for input to FLACS model
110	4	LNG	4018	sendout to truck loading	P4	1" Diameter Hole	1.00	150	FLACS	Design	63	0.000	-258.1	122.3	61,123	leak rate determined by Phast for input to FLACS model
113	8	LNG	4023	sendout to Hylebos	P1	Catastrophic Rupture	8.00	890	FLACS	Design	61	0.000	-259.2	18.2	711,003	leak rate set to run-out flow of two in-tank pumps
131	10	NG	X7	gas sendout to pipeline	P1	Catastrophic Rupture	10.00	560	Phast	Design	73	1.000	64.6	46.4	159,380	leak rate - run-out flow of ex-tank pump
137	10	LNG	4062	sendout to TOTE - dock side	P2	1/3 Diameter Hole	3.33	330	FLACS	Design	65	0.000	-258.1	98.5	598,161	leak rate determined by Phast for input to FLACS model
148	3	LNG	X13	vapor return from TOTE - dock side	-	Catastrophic Rupture	3.00	330	Phast	Off-Design	N/A	1.000	-240.0	17.7	6,284	leak rate determined by Phast
165	2	FG	8007	fuel gas to pre-treatment	P1	Catastrophic Rupture	2.00	320	Phast	Design	N/A	1.000	114.9	69.7	14,233	leak rate determined by Phast
166	2	HL	8008	heavies to storage	P1	Catastrophic Rupture	2.00	270	Phast	Design	N/A	0.000	120.0	34.7	9,800	leak rate determined by Phast

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION - DO NOT RELEASE

Note:

1. Stream conditions and compositions based on design case. Refer to H&M Balance, 186512-PR-01-000101/104.
2. Stream conditions not present in the H&M Balance are obtained from the Design or an appropriate Off-Design simulation model as required.
3. Failure case analyzed represents worst case leak size among all credible failures for a given line.
5. In instances where the calculates leak flow rate exceeds the available supply flow (i.e. run-out pump capacity), the leak pressure has been adjusted to match the sustainable flow rate. This is denoted as the equivalent pressure.

= equivalent pressure used

APPENDIX C – INDEX OF EQUIPMENT CONTAINING HAZARDOUS MATERIALS

Revision:	A												**Job Number:**	186512
Date:	17-Mar-2015												**Document No.**	186512-000-PR-LS-01001
Made By:	LA												**Calculation No.**	
Checked:	JNG	**Client:**												
Office:	PSE	**Project:**												

Index of Equipment Containing Hazardous Materials

Item	Equipment #	Description	P&ID No. (DWG)	Plot Plan DWG No.	Service(s)	Dimensions	Operating Liquid Volume (ft^3)	Design Pressure (psig)	Design Temperature (°F)	Design Capacity / Flow	Duty (MMBTU/HR)	Compressor & Pumps		Comments
												Driver Power (HP)	Shaft Dia.	
VESSELS	F-101	Plant Inlet Filter Separator	010001		NG	30" I.D. x 131" T-T	0.0	285	150	49,100 lb/hr	-	-	-	-
	V-201	Heavy Ends Separator	020001		LNG	24" I.D. x 96" T-T	13.1	675	-150 to 120	41,876 lb/hr	-	-	-	-
	V-209	MRL Distribution Vessel	020001		MRL	24" I.D. x 80" T-T	8.8	675	-320 to 150	201,800 lb/hr	-	-	-	Fives Cryo Quote
	V-202	MRL Compressor Suction Separator	020201		MRL	54" I.D. x 192" T-T	0.0	675	150	303,804 lb/hr	-	-	-	-
	V-203	MRL Compressor 2nd Stage Suction Separator	020302		MRL	60" I.D. x 72" OAH	0.0	675	150	303,804 lb/hr	-	-	-	Part of MRL Compressor Skid
	V-204	MRL Condensate Separator	020101		MRL	72" O.D. x 144" T-T	170.2	675	150	303,804 lb/hr	-	-	-	-
	V-901	Pretreatment - Mercury Removal Vessel	TBD		NG	60" I.D. x 167 T-T	0.0	640	180	49,100 lb/hr	-	-	-	Process Group Quote 03/06/15
	T-901	Pretreatment - Amine Contactor	TBD		NG	42" I.D. x 772" T-T	0.0	640	220	49,100 lb/hr	-	-	-	Process Group Quote 03/06/15
	F-903	Pretreatment - Inlet Filter Coalescer	TBD		NG	20" O.D. x 126" OAL	0.0	640	220	49,100 lb/hr	-	-	-	Process Group Quote 03/06/15
	V-903 A/B	Pretreatment - Molecular Sieve Dryers	TBD		NG	72" O.D. x 196" T-T	0.0	640	550	49,100 lb/hr	-	-	-	Process Group Quote 03/06/15
	F-904 A/B	Pretreatment - Dry Gas Filters	TBD		NG	16" O.D x 70" OAL	0.0	640	180	49,100 lb/hr	-	-	-	Process Group Quote 03/06/15
	V-205	MRL Storage Vessel	021001		MRL	132" O.D. x 690" T-T	1300.0	675	150	5880 ft^3	-	-	-	storage vessel, NNF, vessel is buried, Estimated MaxCapacity
	V-206	Propane Storage Vessel	021002		MRL	52" O.D. x 216" T-T	137.8	250	150	275.7 ft^3	-	-	-	storage vessel, NNF, vessel is buried, op. capacity
	V-207	i-Pentane Storage Vessel	021002		MRL	63" O.D. x 252" T-T	236.8	250	150	473.5 ft^3	-	-	-	storage vessel, NNF, vessel is buried, op. capacity
	V-208	Ethylene Storage Vessel	021003		MRL	66" O.D. x 264" T-T	272.2	675	150	544.5 ft^3	-	-	-	storage vessel, NNF, vessel is buried, op. capacity
	V-301	BOG Compressor Suction Separator	030101		NG	36" O.D. x 84" T-T	0.0	150	-270 to 150	4,030 lb/hr	-	-	-	-
	V-302	Oil Coalescing Filter	030101		NG	TBD	0.0	550	350	4,030 lb/hr	-	-	-	Part of BOG Compressor Skid
	V-351	Flare Knockout Drum	035001		NG	24" I.D. x 60" T-T	2.5	50	-270 to 300	4,400 lb/hr	-	-	-	-
	F-801	Fuel Gas Filter	080101		FG	8" O.D. x 24" OAL	0.0	320	150	4,722 lb/hr	-	-	-	-
	V-801	Fuel Gas Separator Vessel	080101		FG	18" I.D. x 96" T-T	2.5	675	200	1,389 lb/hr	-	-	-	-
	V-802	Heavies Storage Vessel	080201		NGL	72" O.D. x 240" T-T	535.0	150	150	593.76 ft^3	-	-	-	storage vessel, NNF, vessel is buried, op. capacity
	V-951	Emergency Flare Knockout Drum	035101		NG	48" O.D. x 120" T-T	0.0	50	-20 to 300	15,900 lb/hr	-	-	-	-
HEAT EXCHANGERS	EC-101	Feed Gas Compressor Aftercooler	010102		NG	228" L x 94" W	0.0	675	310	49,100lb/hr	4.675	-	-	-
	E-909	Pretreatment - Inlet Gas Cooler	TBD		NG	12" I.D. x 288" OAL	0.0	640	185	49,100 lb/hr	0.795	-	-	Process Group Quote 03/06/15 - BEM S&T HX
	E-201	Heavy Ends Platefin Heat Exchanger	020001		LNG, NG, MRL	186" x 24" x 30.25"	2.49 - MRL	675	-320 to 150	41,876 lb/hr	5.22	-	-	Flow is maximum for a single pass (NG product)
	E-202	Liquefaction Platefin Heat Exchanger	020001		LNG, NG, MRL	324" x 48" x 121.7"	165 - MRL	675	-320 to 150	303,804 lb/hr	83.76	-	-	Flow is maximum for a single pass (MRL refrigerant)
	E-203	MRL Compressor 1st Stage Intercooler	020302		MRL	TBD	0.0	675	375	303,804 lb/hr	7.755			Part of MRL Skid
	EC-204	MRL Fin-Fan Cooler	020101		MRL	684" L x 312" W	0.0	675	330	303,804 lb/hr	39.17	-	-	-
	E-301	BOG Preheater	030001		NG	TBD	0.0	150	-260	4,030 lb/hr	0.3784	-	-	Part of BOG Compressor Skid
	E-302	BOG Compressor Aftercooler	030101		NG	TBD	0.0	600	375	4,030 lb/hr	0.3514			Part of BOG Compressor Skid
	E-306	Tank Vapor Makeup Vaporizer	040102		NG	TBD	0.0	150	-260	1,136 lb/hr	0.3452			-
	E-402	LNG Vaporizer	040203		LNG	134" O.D. x 552" OAL	0.0	420	-270 to 150	119,745 lb/hr	44.9	-	-	Water Bath dimensions
COMPRESSORS & PUMPS	C-101	Feed Gas Compressor	010101		NG	-	-	675	350	49,100 lb/hr	-	2,250	TBD	Temperature upstream of aftercooler
	C-201	MRL Compressor	020301		MRL	-	-	675	350	303,804 lb/hr	-	13,000	TBD	Temperature upstream of aftercooler
	P-401 A/B/C	LNG In-tank Pumps	040101		LNG	-	-	160	-270	288,050 lb/hr	-	150	TBD	Mass flowrate per in-tank pump
	P-402	LNG Vaporization Pump	040201		LNG	-	-	375	-270	119,724 lb/hr	-	120	TBD	-
	C-301 A	Boil-off Gas Compressor	030101		NG	-	-	600	375	2,015 lb/hr	-	300	TBD	Temperature upstream of aftercooler
	C-301 B	Boil-off Gas Compressor	030201		NG	-	-	600	375	2,015 lb/hr	-	300	TBD	Temperature upstream of aftercooler
	C-202	MRL Storage Compressor	021001		MRL	-	-	600	300	150 lb/hr	-	15	TBD	-
	P-802	Heavies Loading Pump	080201		NG	-	-	100	150	8,123 lb/hr	-	10	TBD	-
MISC.	QL-402	LNG Loading Arm w/ Piggyback Vapor Return	040302		LNG	6" NPS	1.0	100	-270	576,100 lb/hr	-	-	-	LNG Fuel Bunkering

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION -
DO NOT RELEASE

Revision:	A		**Index of Equipment Containing Hazardous Materials**										**Job Number:**	186512	
Date:	17-Mar-2015												**Document No.**	186512-000-PR-LS-01001	
Made By:	LA												**Calculation No.**		
Checked:	JNG	**Client:**	Puget Sound Energy												
Office:	PSE	**Project:**	Tacoma LNG												

Item	Equipment #	Description	P&ID No. (DWG)	Plot Plan DWG No.	Service(s)	Dimensions	Operating Liquid Volume (ft^3)	Design Pressure (psig)	Design Temperature (°F)	Design Capacity / Flow	Duty (MMBTU/HR)	Compressor & Pumps		Comments
												Driver Power (HP)	Shaft Dia.	
MISC	-	LNG Truck Dump Sump	040401		LNG	14"	0.0	150	150	5,388 ft^3	-	-	-	-
	U-405	Dual Truck Loading Skid	040401		LNG	3" NPS x 60 L	2.0	100	-270	65,354 lb/hr	-	-	-	Operating Liquid Volume of Two (2) Hoses
TANK	TK-401	LNG Storage Tank on Isolators Full Concrete Containment	040001		LNG	124' I.D. x 100'-7.5" H	1,069,444	3	-270	Net Storage 8,000,000 gallons	-	-	-	Dimensions for Inner Tank 144' O.D. x 113'-2" Concrete Outer Wall Height

Note:

1. All Items are Preliminary
2. Refer to Plot Plan Dwg. 186512-000-PI-01-00001 for location of all items.

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION -
DO NOT RELEASE

APPENDIX D – LIMITED SOURCE SPILL RATE CALCULATIONS

CB&I		**Spill Rate Calculations - Piping Items 113 & 25**		PSE PUGET SOUND ENERGY	
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01006
Made By:	JG			**Calc No.**	
Checked:	GCB	**Client:**	Puget Sound Energy	**Sheet**	1 of 1
Office:	PSE	**Project:**	Tacoma LNG		

Calculate Run Out Flow Rate for Piping Item No. 113 (Gexcon Cases 7, 8 & 9)

Per PHMSA direction (see website FAQ), spill scenarios are to consider pump run out conditions .

Hylebos LNG Supply Line

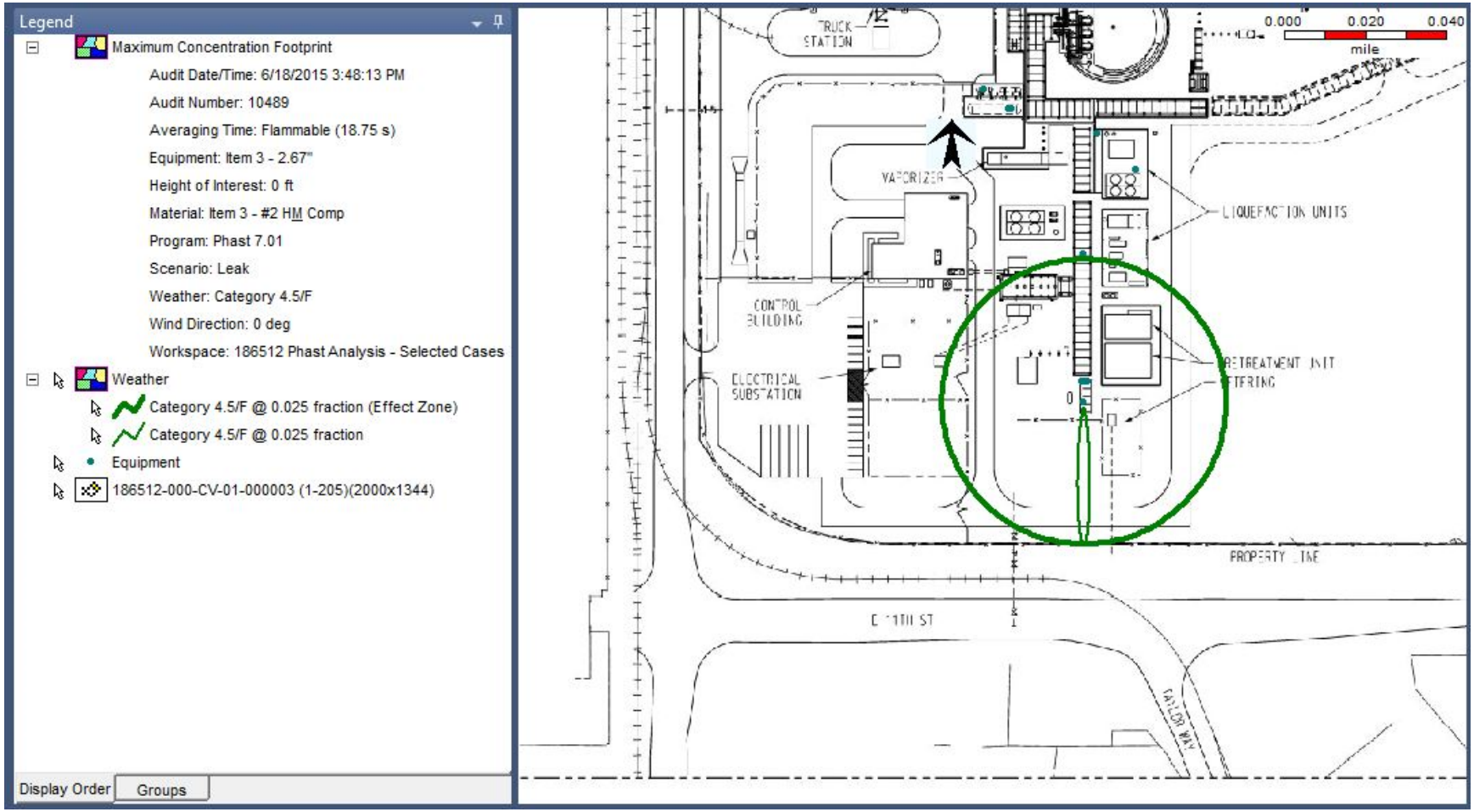
In-Tank Pump Runout Flow (q_r)		1,630	gpm	per Ebara: Mar. 18, 2015 - Proposal No.: 13156A-1US
No of Pumps Running (n)		2		required for ship bunkering
Maximum Total Flow (Q)		3,260	gpm	= q_r * n
		26,148	ft^3/hr	
Spill Duration (t)		10	minutes	per NFPA 59A: Chap. 5 Plant Siting & Layout
Spill Volume (V)		32,600	gallons	= Q * t
		4,358	ft^3	
Density (ρ)		27.19	lb/ft^3	H&MB Stream #12
Mass Flow Rate (W)		**711003**	**lb/hr**	= Q * ρ
Total Spill Mass		118501	lb	= W * t
Tank Static Head	h	92	ft	tank HLL
Pump Suction Pressure	Ps	32.1	psia	=h * ρ * 1 ft^2 / 144 in^2 + 14.7 psia
Pump Head at Runout	H	500	ft	per Ebara: Mar. 18, 2015 - Proposal No.: 13156A-1US
Pump Delta P	DP	94.4	psid	=H * ρ * 1 ft^2 / 144 in^2
Max. Pump Discharge Pressure	Pd	126.5	psia	=Ps + DP

Calculate Flow for LNG Rundown Line, Piping Item No. 25 (Gexcon Case 6)

Liquefaction cannot be sustained at theoretical leak flow rates. To generate a worst case 10 minute liquid LNG spill, the flow rate is governed by the liquefaction capacity of the facility plus 10% excess.

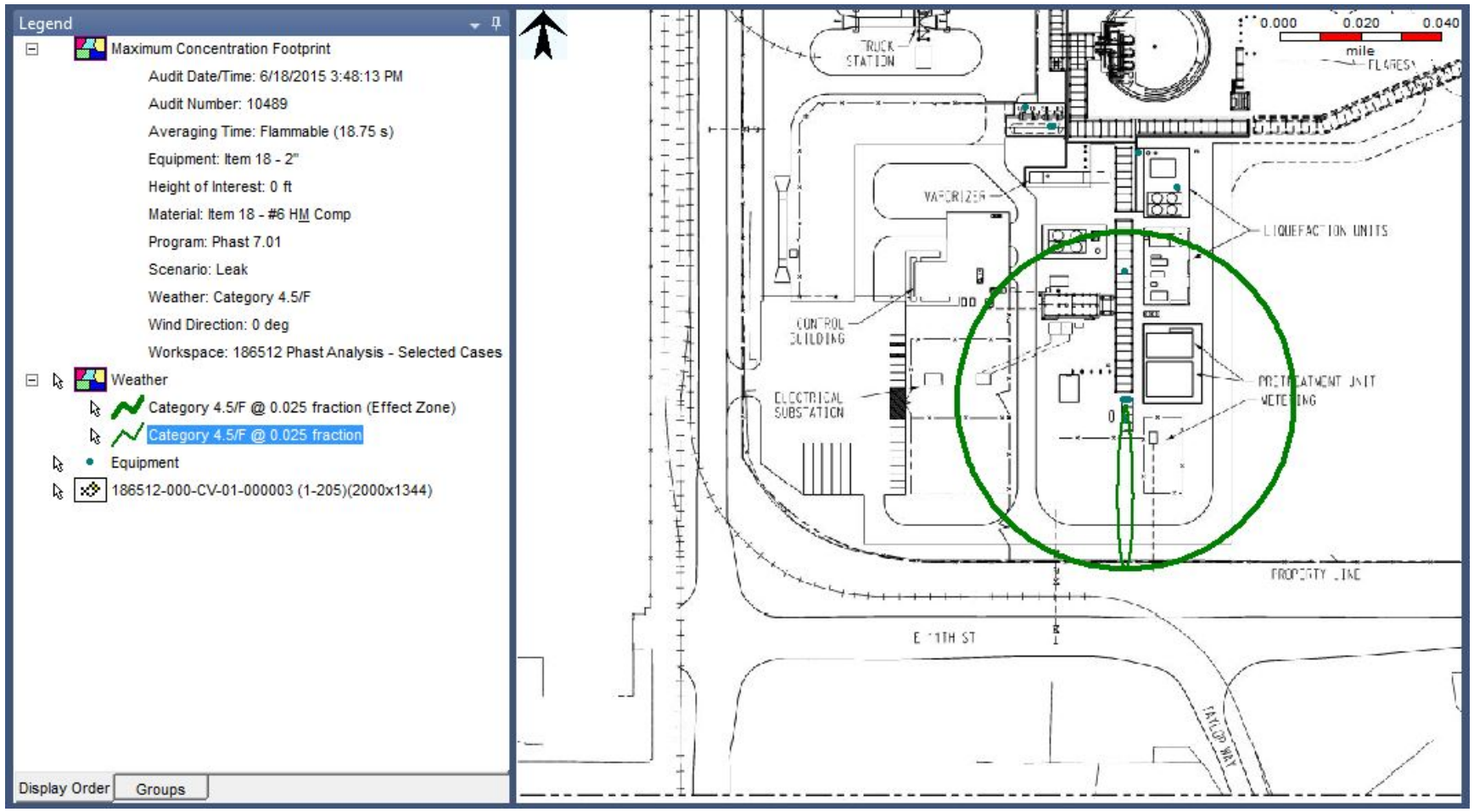
Design Liquefaction Flow Rate	45,444	lb/hr	H&MB Stream #11
Excess	10%		
Mass Flow Rate (W)	**49988**	**lb/hr**	
Spill Duration (t)	10	minutes	per NFPA 59A: Chap. 5 Plant Siting & Layout
Total Spill Mass	8331	lb	= W * t

APPENDIX E – PHAST ANALYSIS RESULTS: VAPOR DISPERSION PLOTS



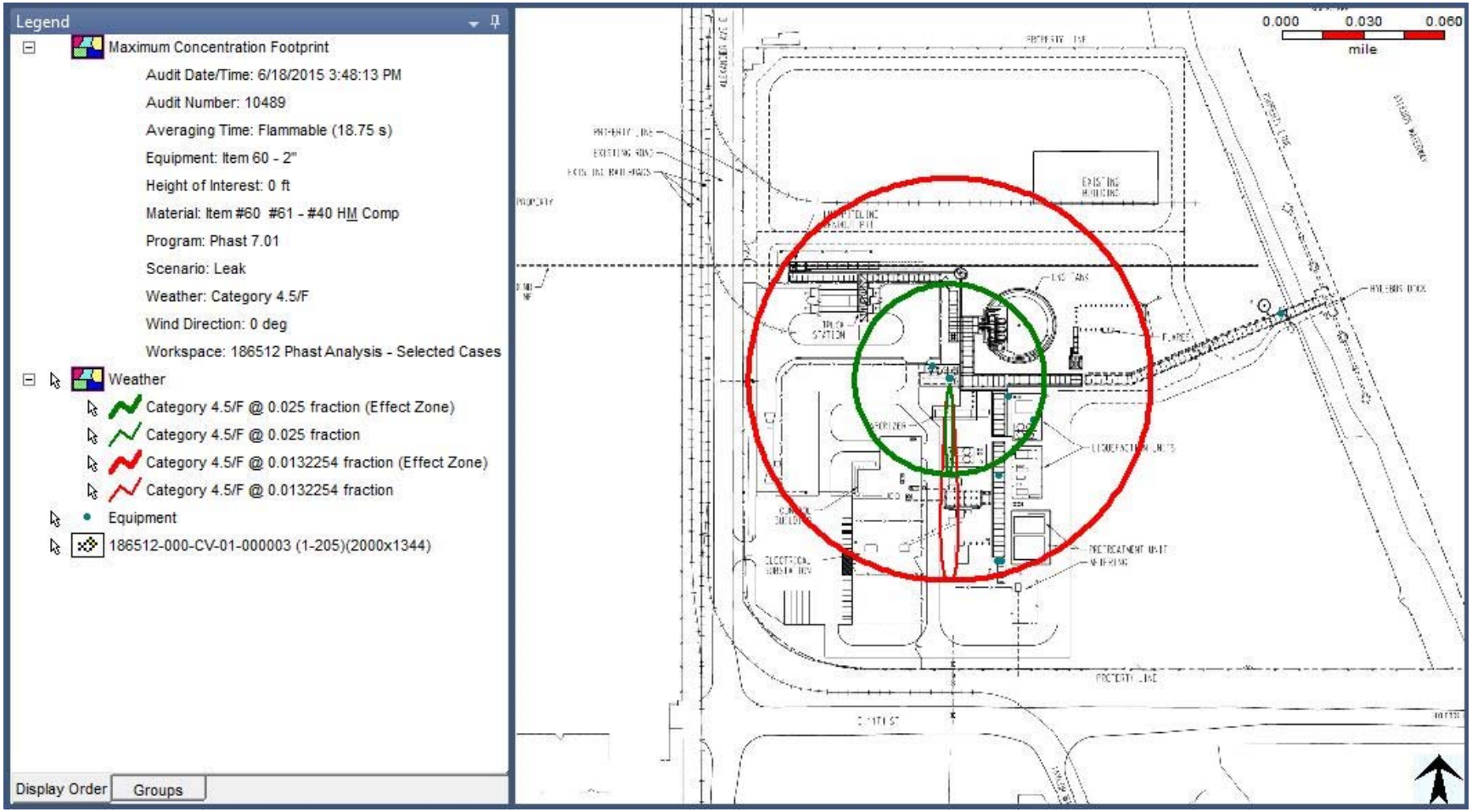
ITEM 3: 2.67” Diameter Leak in Plant Inlet NG Line (8”-NG-1002)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



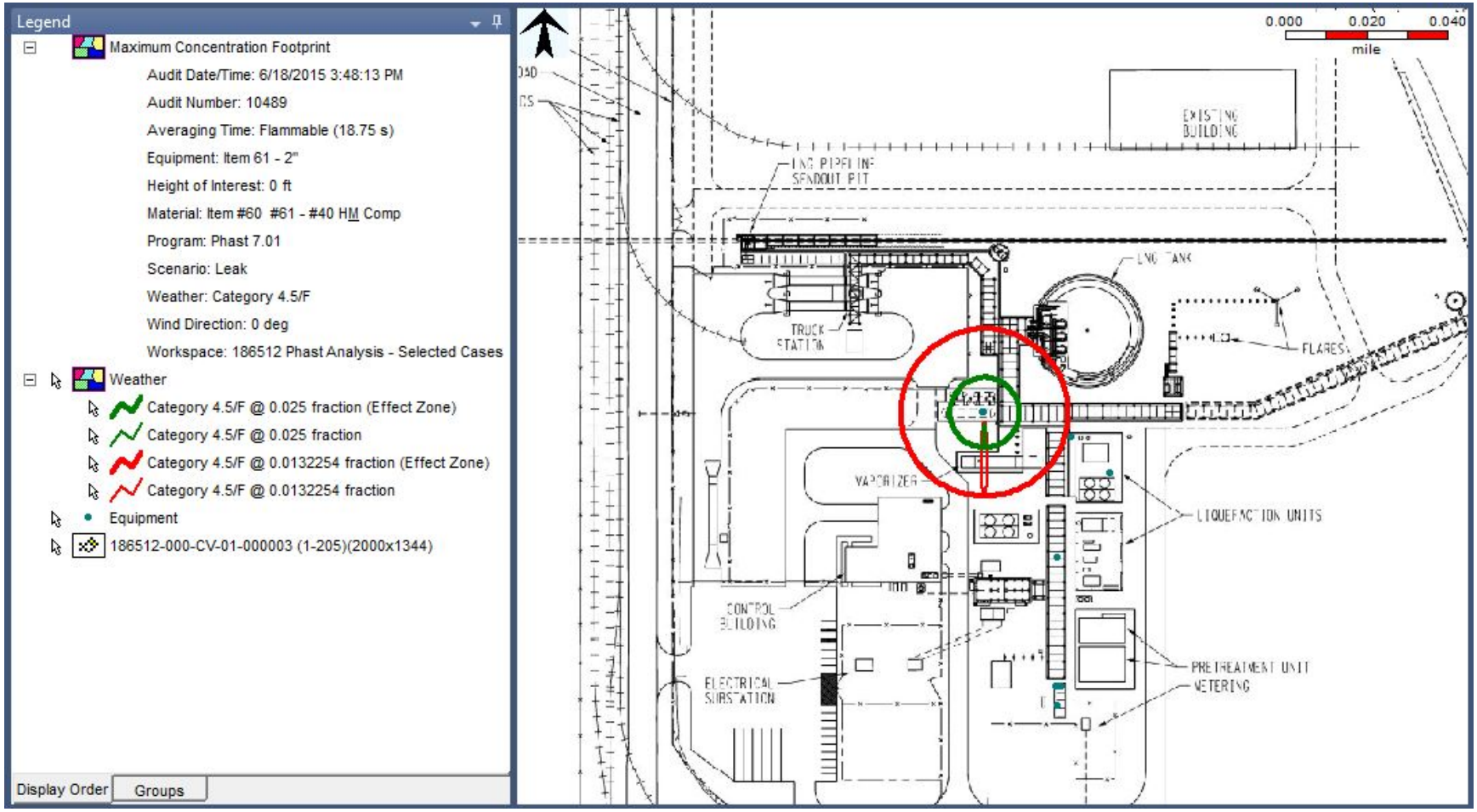
ITEM 18: 2” Diameter Leak in NG Line From Pre-Treatment to Liquefier (6”-NG-1010)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



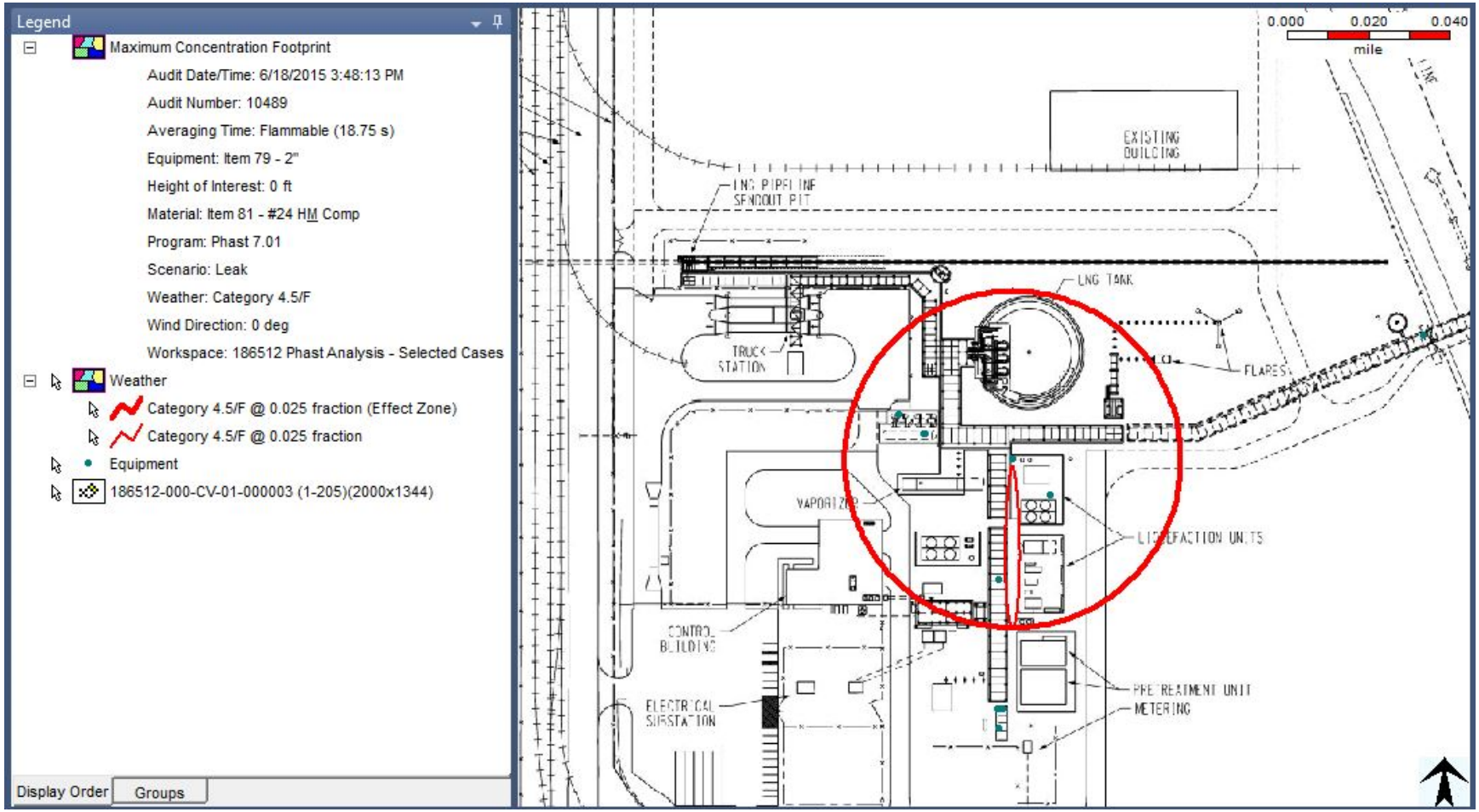
ITEM 60: 2” Diameter Rupture of Refrigerant Make-up Line From MRL Storage to Liquefaction Area (2”-MR-2101)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



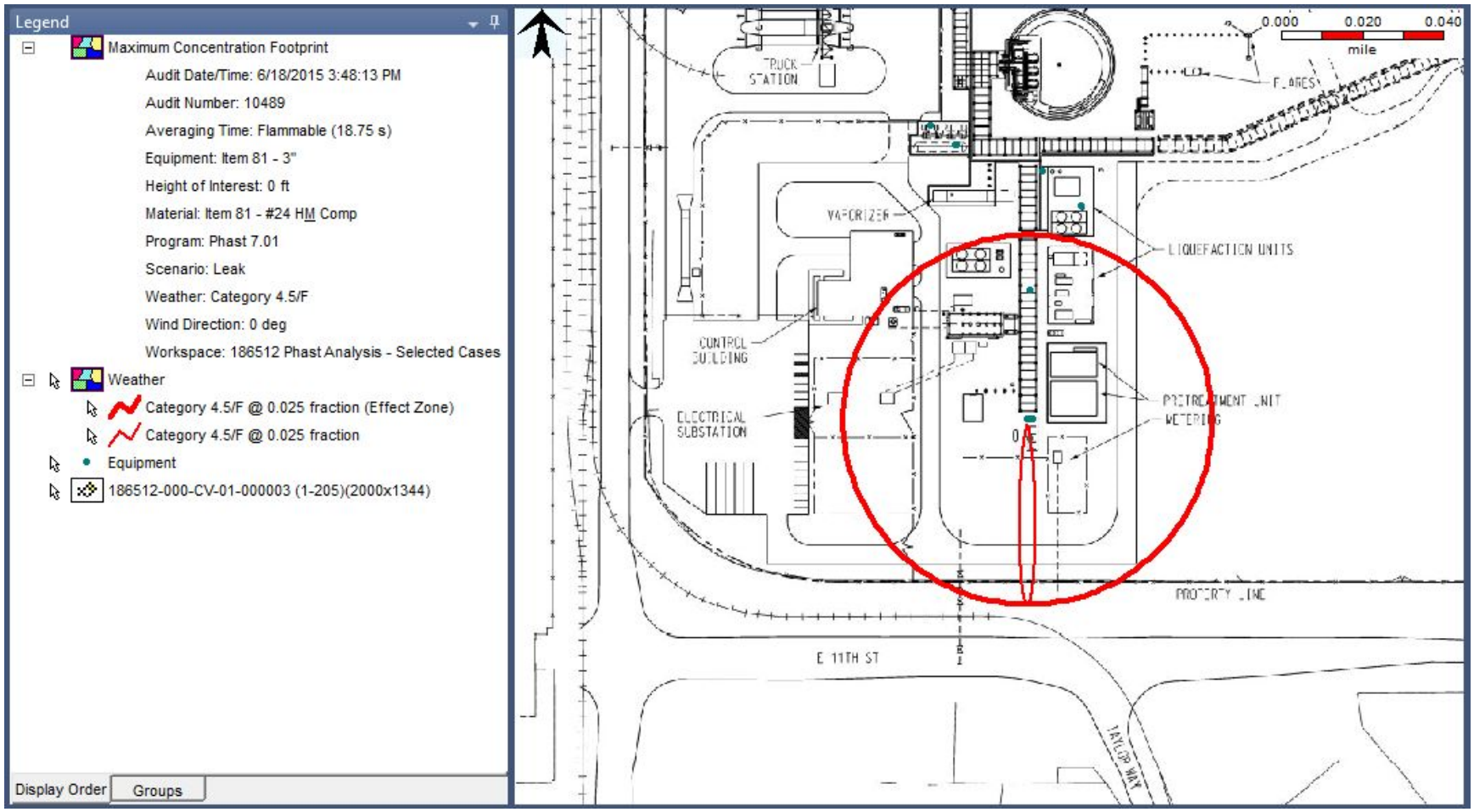
ITEM 61: 2” Diameter Rupture of Refrigerant Make-up Line From Liquefaction Area to MRL Compressor Suction Separator (2”-MR-2102)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



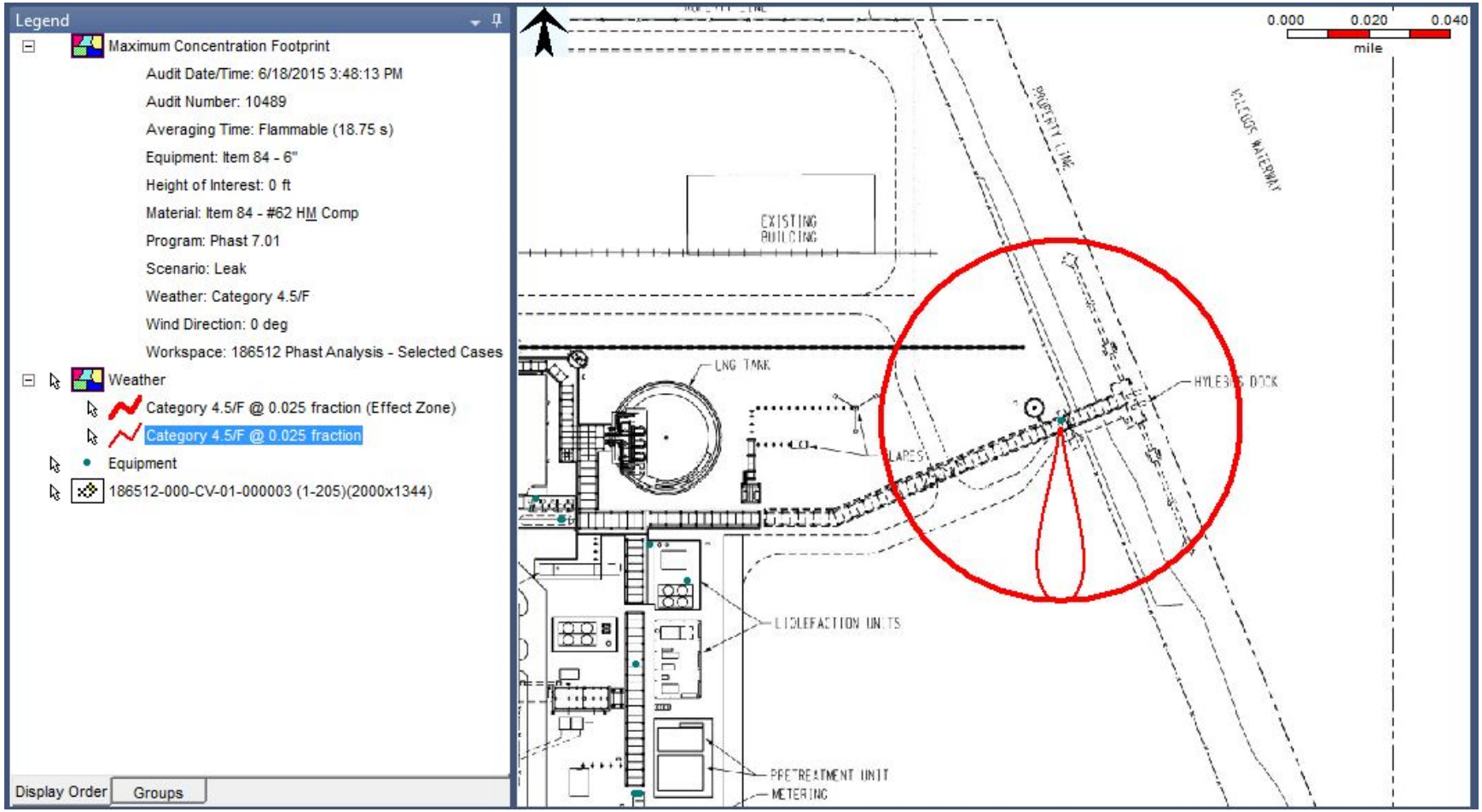
ITEM 79: 2” Diameter Rupture of Compressed Boil-Off Gas Line to Fuel Gas Supply (2”-NG-3008)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



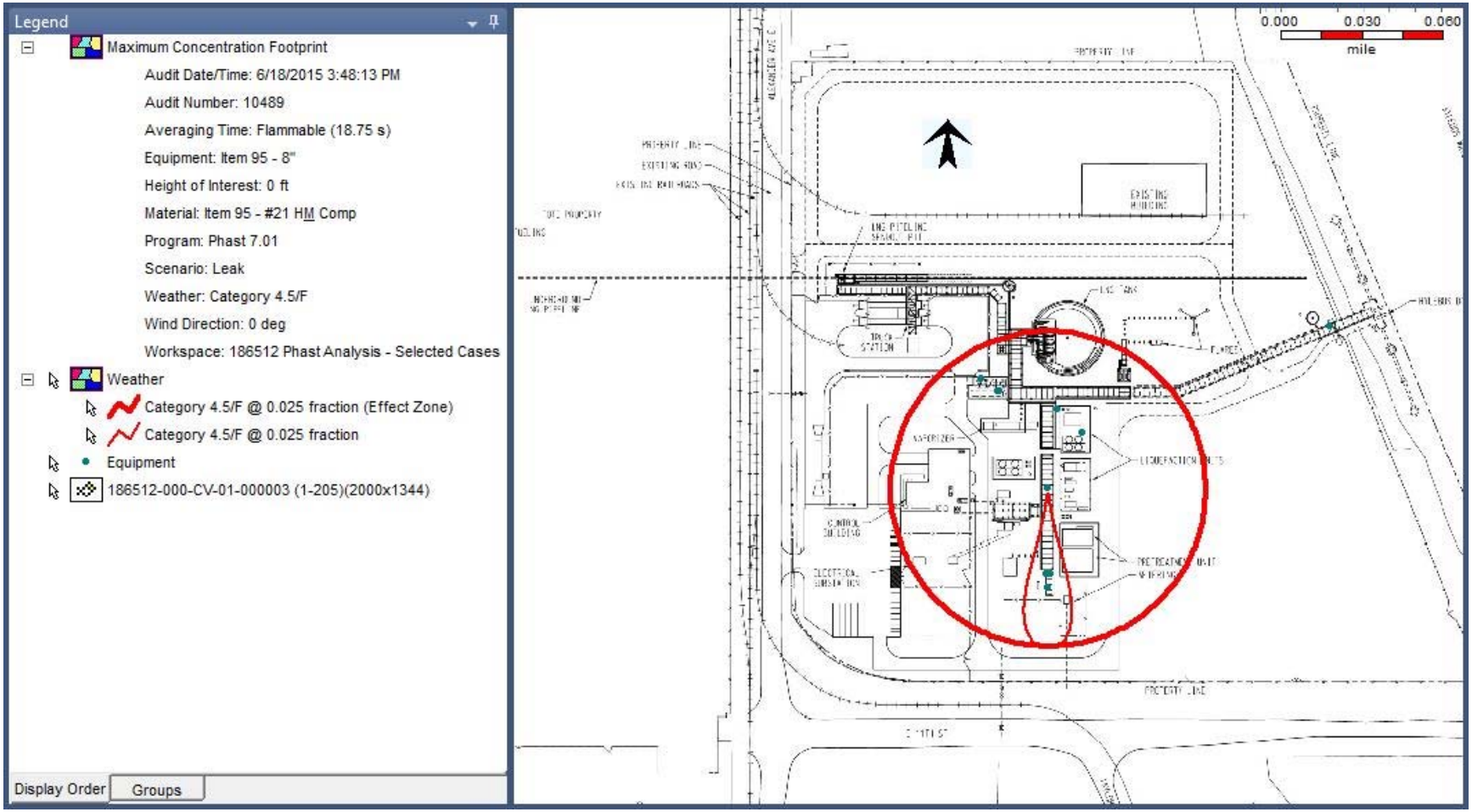
ITEM 81: 3” Diameter Rupture of Compressed Boil-Off Gas Line to Pipeline Supply (3”-NG-3010)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



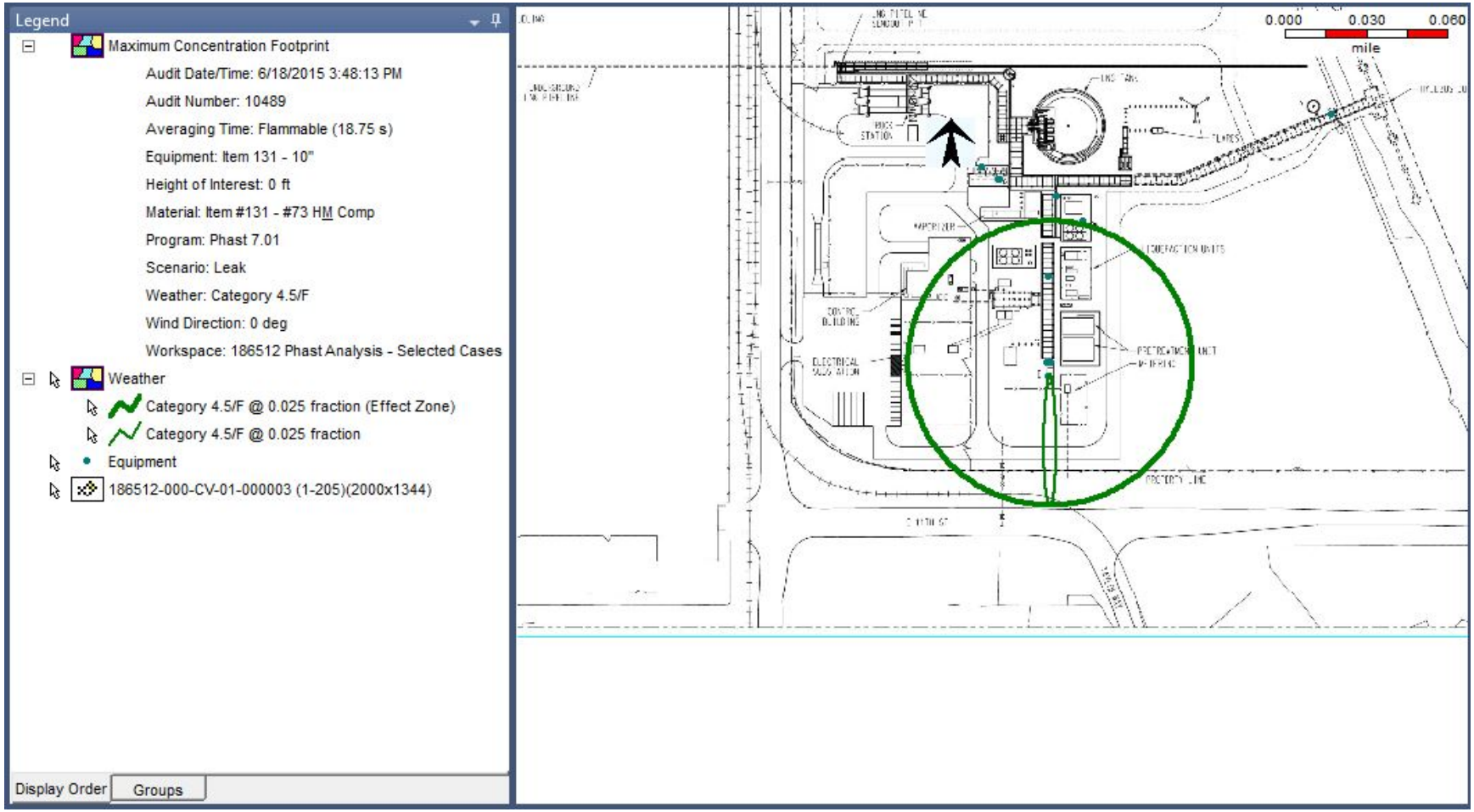
ITEM 84: 6” Diameter Rupture of Vapor Return Line From Hylebos Dock (6”-LNG-4036)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



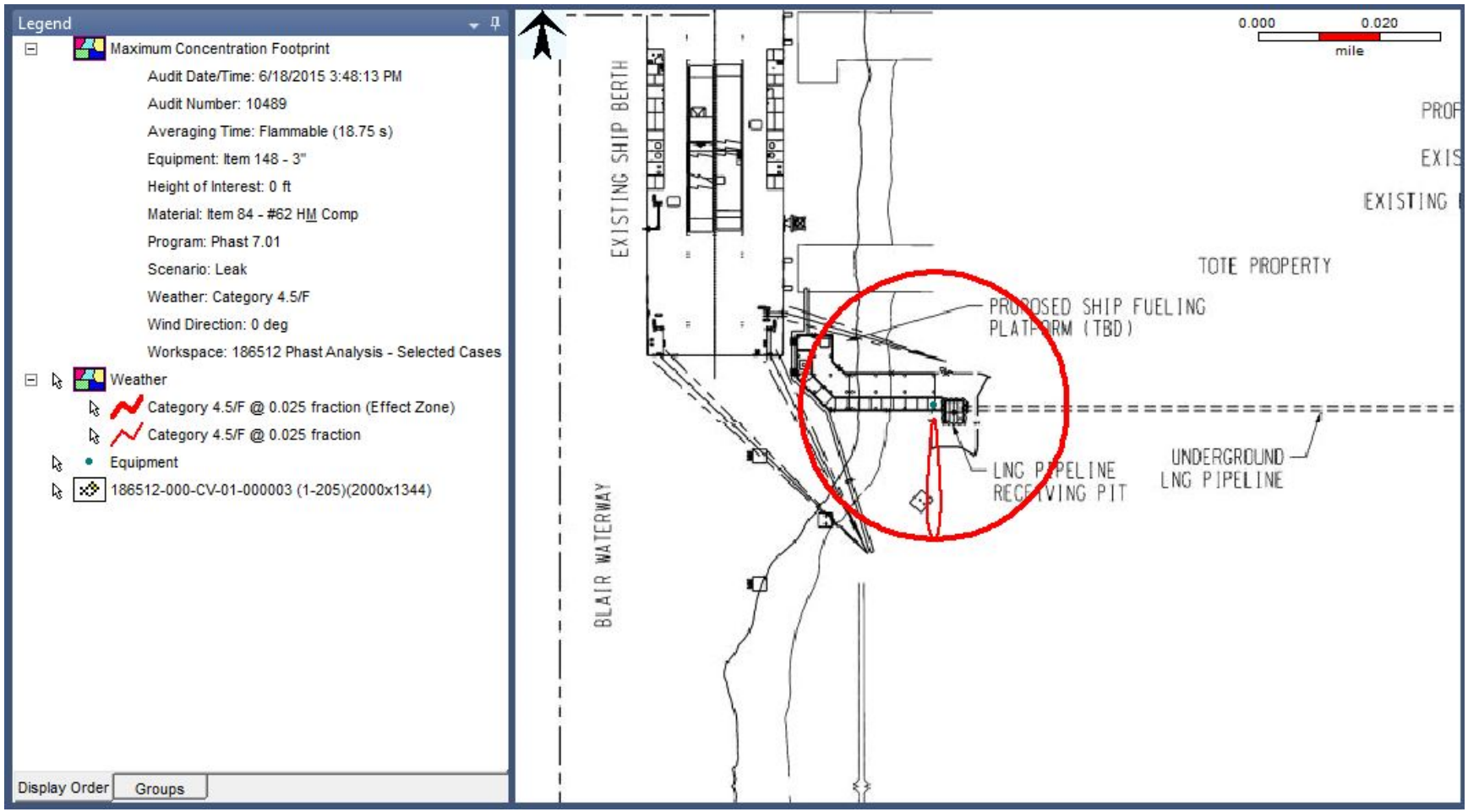
ITEM 95: 8” Diameter Rupture of Boil-Off Gas Vapor Header (8”-BOG-3001)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



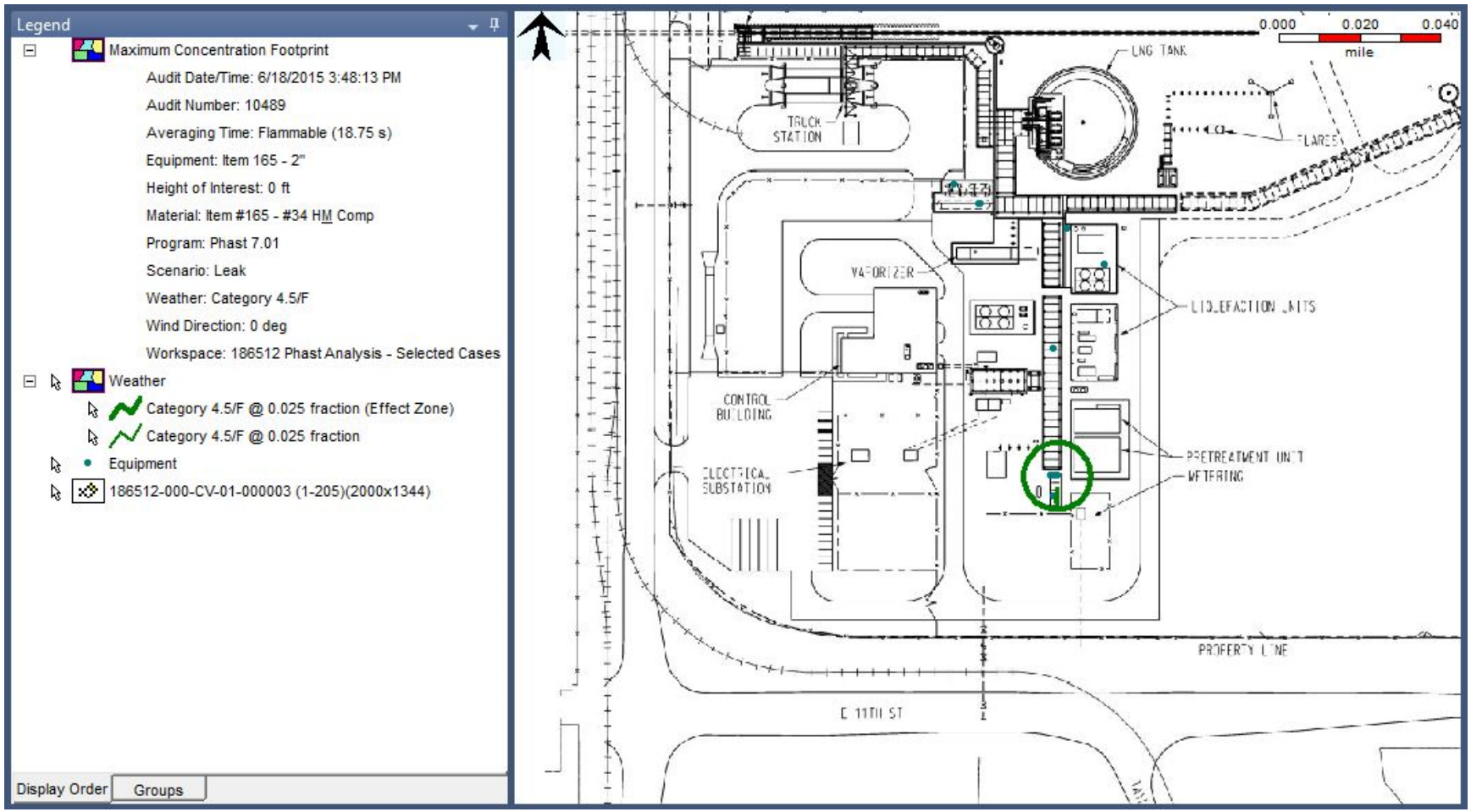
ITEM 131: 10” Diameter Rupture of Gas Sendout to Pipeline (10”-NG-X7)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



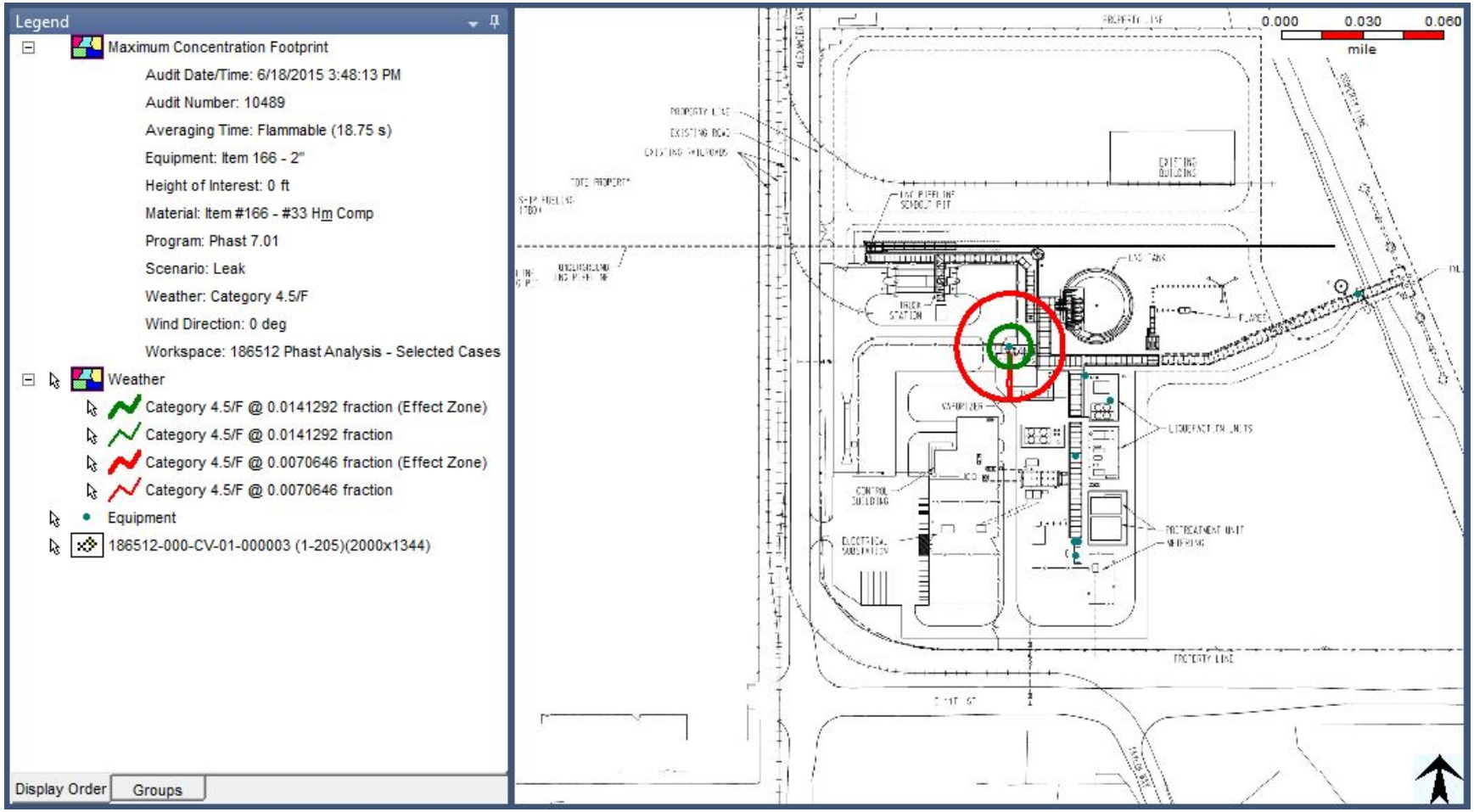
ITEM 148: 3” Diameter Rupture of Vapor Return Line at TOTE Facility (3”-LNG-X13)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



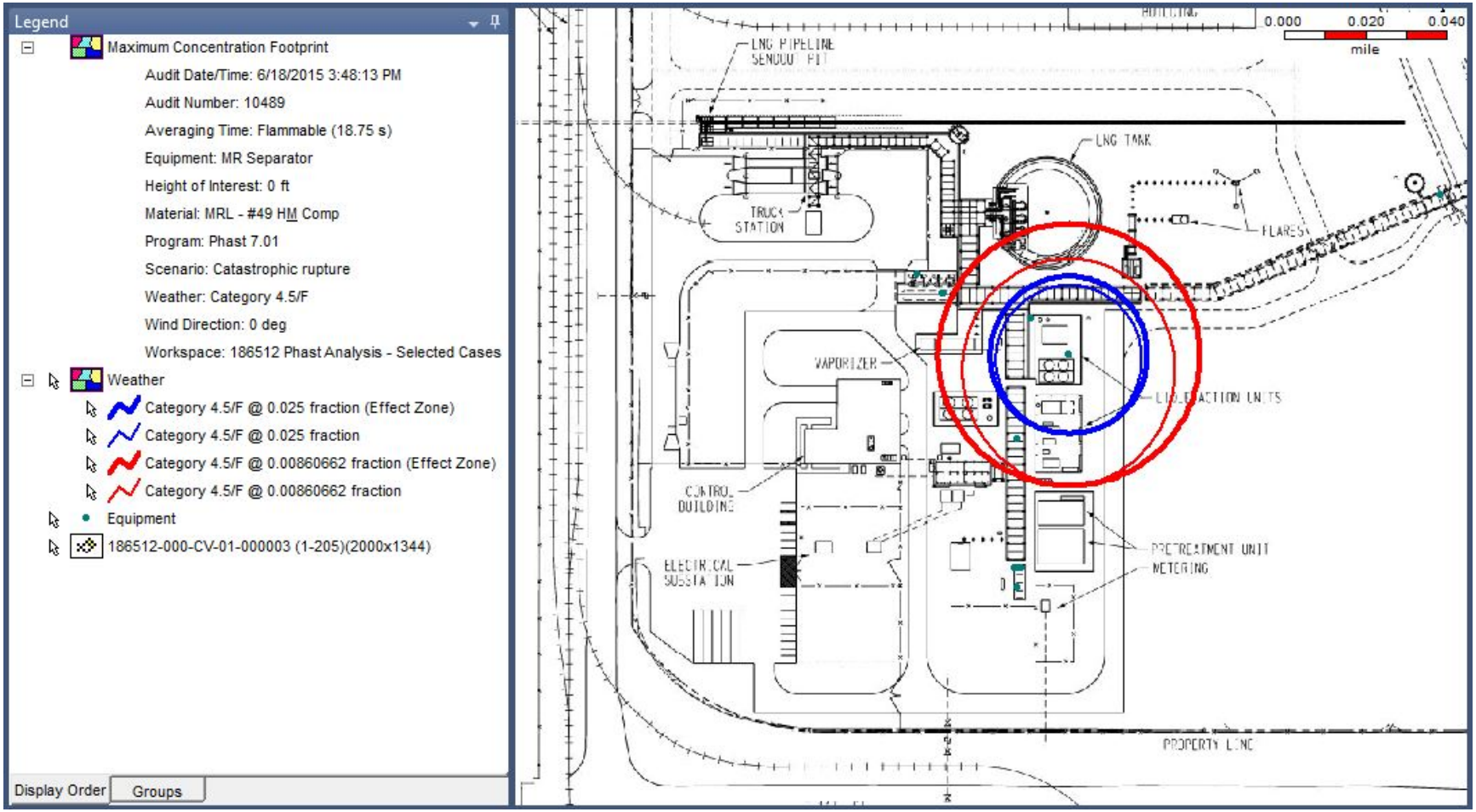
ITEM 165: 2” Diameter Rupture of Fuel Gas Supply to Pre-Treatment (2”-FG-8007)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



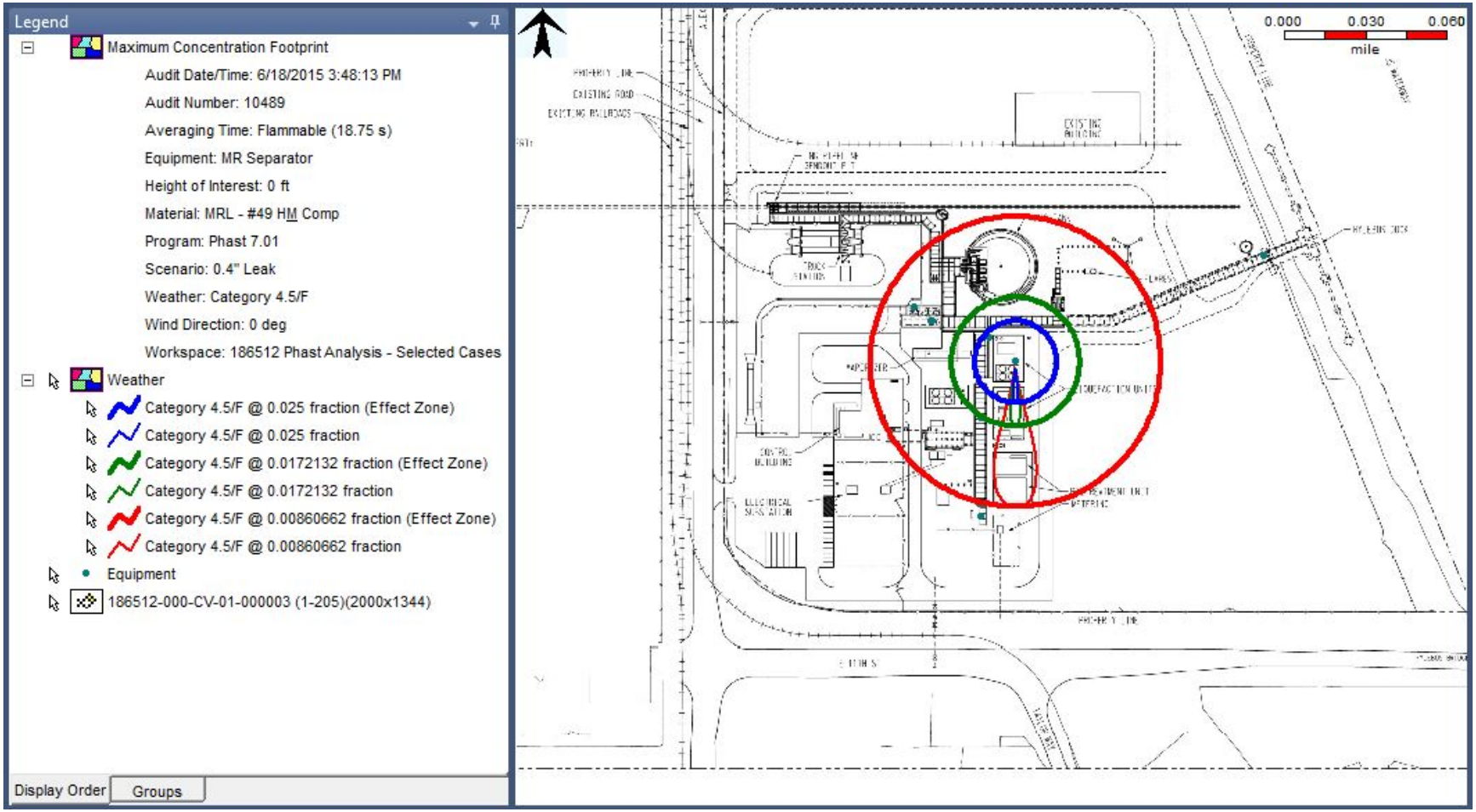
ITEM 166: 2” Diameter Rupture of Heavies Transfer Line to Heavy Ends Storage Vessel (2”-HL-8008)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



VESSEL V-204: Catastrophic Rupture of MRL Condensate Separator Vessel (V-204)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE



VESSEL V-204: 0.4” Diameter Leak in MRL Condensate Separator Vessel (V-204)

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

APPENDIX F – LNG TANK CONTAINMENT, SPILL IMPOUNDMENT & TRENCH SIZING CALCULATIONS

LNG Tank: Outer Concrete Tank Containment Volume

Revision:	B			**Job No:**	186512
Date:	15-Jul-2015			**Doc No.**	186512-000-PR-CL-01007
Made By:	GCB			**Calc No.**	
Checked:	MES	**Client:**	Puget Sound Energy	**Sheet**	1 of 1
Office:	PSE	**Project:**	Tacoma LNG		

.

Maximum Inner Tank Liquid Volume

Inner Tank Height	H_i	95.67	ft	
Design Liquid Level in Tank	DLL	86.25	ft	
Inner Tank ID	ID_i	129	ft	
Maximum Liquid Volume	V_i	1,127,271	ft^3	= π /4 * ID_i^2 * DLL
		8,430,000	gallons	

Gross Excess Outer Tank Capacity

Outer Tank Height	H_o	103.5	ft	
Outer Tank ID	ID_o	135.5	ft	
Annular Space Volume	V1	129,178	ft^3	= π /4 * (ID_o^2 - ID_i^2) * H_i
Height from top of Outer Tank to DLL	h	17.25	ft	= H_o - DLL
Volume of Outer Tank above DLL	V2	248,747	ft^3	= π /4 * ID_o^2 * h

Outer Tank Volume Displacements

Perlite Void Volume	v	50%		Note 1
Annular Space Perlite Volume	V3	64,589	ft^3	= V1 * (1 - v)
Inner Tank Roof Deck Plate Thickness	t_p	0.5	in	Note 2
Inner Tank Roof Deck Plate Volume	V4	545	ft^3	= π /4 * ID_i^2 * t_p
Deck Fiberglass Blanket Thickness	t_f	1.67	ft	
Fiberglass Void Volume	v_f	98%		
Solid Volume of Fiberglass Blanket	V5	436	ft^3	= π /4 * ID_i^2 * t_f * (1-v_f)

Piping Penetration Volumes — Note 3

Pipe Size (in)	Qty	Volume (ft^3)	
6	5	17	= π /4 * (Pipe Size)^2 * h * Qty
8	1	6	
12	2	27	
24	4	217	
SUM	V6	267	ft^3

Net Excess Outer Tank Volume

Total Excess Volume Available in Outer Tank	V_tot	312,089	ft^3	= V1 + V2 - V3 - V4 - V5 - V6
Excess Volume as a % of Inner Tank Volume		28%		
Total Outer Tank Volume		1,439,360	ft^3	
		10,770,000	gallons	

NOTES

1. The perlite in the annulus of the tank has a void volume of approximately 90%. Although liquid can enter the void volume of the perlite, the perlite will be assumed to have a void volume of 50% for conservatism in calculating the liquid retaining volume in the annular space.
2. 1/2" deck plate thickness is used to account for vent and support rod volumes.
3. The total volume of all pipes which penetrate the roof of the inner tank will be subtracted from the maximum liquid level to the top of the out tank shell (h).

Spill Impoundment Sizing & Thermal Radiation Calculations

Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:	JG	**Client:**	Puget Sound Energy	**Sheet**	1 of 7
Office:	PSE	**Project:**	Tacoma LNG		

PROCESS SUMP SPILL IMPOUNDMENT SIZING

In-Tank Pump Runout Flow	1,630	gpm	per Ebara: Mar. 18, 2015 - Proposal No.: 13156A-1US
No of Pumps Running	3		
Maximum Total Flow (Q)	4,890	gpm	
Spill Duration	10	minutes	per NFPA 59A: Chap. 5 Plant Siting & Layout
Spill Volume	48,900	gallons	
	6,537	ft^3	
LNG Supply Header Volume	224	ft^3	Line 10"-4007
TOTE Supply Header Volume	191	ft^3	Line 10"-4017
Hylebos Supply Header Volume	311	ft^3	Line 8"-4023
Minimum Impoundment Volume	7262	ft^3	
Sump Diameter	22.25	ft	
Sump Surface Area	388.8	ft^2	

Minimum Usable Sump Depth	18.7	ft	from invert of trench
Actual Usable Sump Depth	19.0	ft	
Trench Depth	2.00	ft	from trench sizing calculations
Gross Sump Depth	**21.0**	**ft**	
Density (ρ)	27.20	lb/ft^3	H&MB Stream #12
Mass Spill Rate	1,066,838	lb/hr	= Q * ρ * (60 min/hr) / (7.48 gallons/ft^3)

SPILL IMPOUNDMENT THERMAL RADIATION CALCULATION SUMMARY

LNGFIRE3 Input

Pool Diameter	22.25	ft	
Height of Flame Base	0.0	ft	
Height of Target	0.0	ft	
Wind Speed	15.6	mph	Design Basis (186512-000-PR-DB-00001)
Tavg[Dec]	38.8	°F	ASHRAE 2013 Station Data - McChord AFB
MCDBR	13.7	°F	ASHRAE 2013 Station Data - McChord AFB
Radiation Temp	31.95	°F	= Tavg[Dec] - MCDBR/2
Relative Humidity	57.2	%	ASHRAE 2013 Station Data - McChord AFB
MW	16.62	lb/lbmol	H&MB Stream #12
Density	27.20	lb/cuft	
Fluid Temp.	198.57	°R	H&MB Stream #12

LNGFIRE3 Output

NFPA 59A Radiant Heat Flux Level	Exclusion Distance
10,000 Btu/hr-ft^2	75.2 ft
3,000 Btu/hr-ft^2	105 ft
1,600 Btu/hr-ft^2	125.6 ft

Per PHMSA direction (see website FAQ), spill scenarios are to consider pump run out conditions and also pipe / vessel de-inventory.
For the Process & Hylebos Spill Sumps, it is assumed that a break in the main supply line will cause the tank header and main E-W pipe rack header to drain out. The underground section and line on the TOTE dock will be prevented from draining to these sumps due to gravity head.

		Spill Impoundment Sizing & Thermal Radiation Calculations			
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:	JG	**Client:**	Puget Sound Energy	**Sheet**	2 of 7
Office:	PSE	**Project:**	Tacoma LNG		

HYLEBOS DOCK SPILL IMPOUNDMENT SIZING

In-Tank Pump Runout Flow	1,630	gpm	per Ebara: Mar. 18, 2015 - Proposal No.: 13156A-1US
No of Pumps Running	2		
Maximum Total Flow (Q)	3,260	gpm	
Spill Duration	10	minutes	per NFPA 59A: Chap. 5 Plant Siting & Layout
Spill Volume	32,600	gallons	
	4,358	ft^3	
LNG Supply Header Volume	224	ft^3	Line 10"-4007
TOTE Supply Header Volume	191	ft^3	Line 10"-4017
Hylebos Supply Header Volume	311	ft^3	Line 8"-4023
Minimum Impoundment Volume	5083	ft^3	
Sump Diameter	22.25	ft	
Sump Surface Area	388.8	ft^2	
Minimum Usable Sump Depth	13.1	ft	from invert of trench
Actual Usable Sump Depth	13.5	ft	
Trench Depth	1.50	ft	from trench sizing calculations
Gross Sump Depth	**15.0**	**ft**	
Density (ρ)	27.32	lb/ft^3	H&MB Stream #12
Mass Spill Rate	714,363	lb/hr	= Q * ρ * (60 min/hr) / (7.48 gallons/ft^3)

SPILL IMPOUNDMENT THERMAL RADIATION CALCULATION SUMMARY

LNGFIRE3 Input

Pool Diameter	22.25	ft	
Height of Flame Base	0.0	ft	
Height of Target	0.0	ft	
Wind Speed	15.6	mph	Design Basis (186512-000-PR-DB-00001)
Tavg[Dec]	38.8	°F	ASHRAE 2013 Station Data - McChord AFB
MCDBR	13.7	°F	ASHRAE 2013 Station Data - McChord AFB
Radiation Temp	31.95	°F	= Tavg[Dec] - MCDBR/2
Relative Humidity	57.2	%	ASHRAE 2013 Station Data - McChord AFB
MW	16.62	lb/lbmol	H&MB Stream #12
Density	27.32	lb/cuft	
Fluid Temp.	198.57	°R	H&MB Stream #12

LNGFIRE3 Output

NFPA 59A Radiant Heat Flux Level	Exclusion Distance
10,000 Btu/hr-ft^2	75.2 ft
3,000 Btu/hr-ft^2	105 ft
1,600 Btu/hr-ft^2	125.6 ft

Per PHMSA direction (see website FAQ), spill scenarios are to consider pump run out conditions and also pipe / vessel de-inventory.
For the Process & Hylebos Spill Sumps, it is assumed that a break in the main supply line will cause the tank header and main E-W pipe rack header to drain out. The underground section and line on the TOTE dock will be prevented from draining to these sumps due to gravity head.

		Spill Impoundment Sizing & Thermal Radiation Calculations			
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:	JG	**Client:**	Puget Sound Energy	**Sheet**	3 of 7
Office:	PSE	**Project:**	Tacoma LNG		

TOTE SPILL IMPOUNDMENT SIZING (FACILITY AND DOCK SIDE SUMPS)

Mass Spill Rate (W)	665,710	lb/hr	Determined from Phast leak analysis
Density (ρ)	27.32	lb/ft^3	H&MB Stream #12
Maximum Total Flow (Q)	3,038	gpm	= W / ρ / (60 min/hr) * (7.48 gallons/ft^3)
Spill Duration	10	minutes	per NFPA 59A: Chap. 5 Plant Siting & Layout
Spill Volume	30,380	gallons	
	4,061	ft^3	
LNG Supply Header Volume	224	ft^3	Line 10"-4007
TOTE Supply Header Volume	191	ft^3	Line 10"-4017
Hylebos Supply Header Volume	311	ft^3	Line 8"-4023
TOTE Supply Line Volume	180	ft^3	Line 10"-4062
Minimum Impoundment Volume	4966	ft^3	
Sump Length	18.86	ft	
Sump Width	14.60	ft	
Sump Surface Area	275.4	ft^2	
Minimum Usable Sump Depth	18.0	ft	from invert of trench
Actual Usable Sump Depth	18.5	ft	
Trench Depth	1.50	ft	from trench sizing calculations
Gross Sump Depth	**20.0**	**ft**	

SPILL IMPOUNDMENT THERMAL RADIATION CALCULATION SUMMARY

LNGFIRE3 Input

Sump Length	18.86	ft	
Sump Width	14.60	ft	
Height of Flame Base	0.0	ft	
Height of Target	0.0	ft	
Wind Speed	15.6	mph	Design Basis (186512-000-PR-DB-00001)
Tavg[Dec]	38.8	°F	ASHRAE 2013 Station Data - McChord AFB
MCDBR	13.7	°F	ASHRAE 2013 Station Data - McChord AFB
Radiation Temp	31.95	°F	= Tavg[Dec] - MCDBR/2
Relative Humidity	57.2	%	ASHRAE 2013 Station Data - McChord AFB
MW	16.62	lb/lbmol	H&MB Stream #12
Density	27.32	lb/cuft	
Fluid Temp.	198.57	°R	H&MB Stream #12

LNGFIRE3 Output

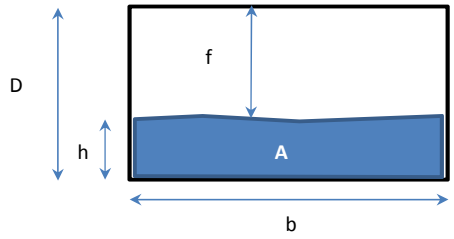
NFPA 59A Radiant Heat Flux Level	Exclusion Distance
10,000 $Btu/hr-ft^2$	68.75 ft
3,000 $Btu/hr-ft^2$	91 ft
1,600 $Btu/hr-ft^2$	106.25 ft

Per PHMSA direction (see website FAQ), spill scenarios are to consider pump run out conditions and also pipe / vessel de-inventory.
For the TOTE Spill Sump & TOTE Sendout Sump, it is assumed that a break in the supply line in the pit will cause the tank header, E-W pipe rack header and loading arm supply line to drain out. The underground section will be prevented from draining becuase the outlet will be submerged. The pipe entrance to the transition pit/sumps is currently designed to have a high point loop, which will prevent the lines on the pipe rack from draining into the pit. The piping volumes have been included to provide conservatism.
The sump pit depth has been limited to 20 ft, based on preliminary information regarding pit working depths required for microtunneling.

		Spill Impoundment Sizing & Thermal Radiation Calculations			
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:	JG	**Client:**	Puget Sound Energy	**Sheet**	4 of 7
Office:	PSE	**Project:**	Tacoma LNG		

Main N-S Spill Trench Sizing (North of E-W pipe rack)

A concrete trench will be provided from the main pipe rack to the process area spill sump to convey the design spill to the sump. The design spill flow rate is based on the run out flow rate of three in-tank pumps.
The following open channel flow calculation is based on the method from Mark's Handbook, 11th Edition, page 3-59.



Trench Design Volumetric Flow	Q	4890	gpm	10.89 ft^3/s
Channel Width	b	2	ft	
Roughness Factor for Unfinished Concrete [1]	n	0.015		
Slope of Trench [2]	S	0.002	Dh / unit L	
Flowing Liquid Depth in Channel	h	**1.679**	ft	goal seek value
Flowing Liquid Cross-Sectional Area	A	3.357	ft^2	*A = b * h*
Hydraulic Radius of Trench	R_h	0.627		$R_h = \frac{bh}{2h+b}$
Manning relation for Chézy coef.- open channel flow	C	91.64		$C = \frac{1.486}{n} R_h^{1/6}$
Velocity	V1	3.25	ft/s	$V_1 = Q/A$
Velocity	V2	3.24	ft/s	$V_2 = C\sqrt{R_h S}$
	V1 - V2	0.0006		set to zero by varying h
Design Trench Depth	D	2.5	ft	
		TRENCH DEPTH OK		
Trench Freeboard	f	9.9	in	f = D - h

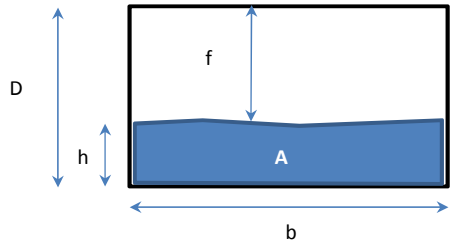
NOTES:
1. Roughness factor is conservative, as this value is based on water. Boiling LNG will have less frictional resistance.
2. 0.2% or 2 ft fall in 1,000 ft run.

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

		Spill Impoundment Sizing & Thermal Radiation Calculations			
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:		**Client:**	Puget Sound Energy	**Sheet**	5 of 7
Office:	PSE	**Project:**	Tacoma LNG		

E-W Spill Trench Sizing

A concrete trench will be provided from the main pipe rack to the process area spill sump to convey the design spill to the sump. The design spill flow rate is based on the largest credible spill scenario for the LNG loading lines.
The following open channel flow calculation is based on the method from Mark's Handbook, 11th Edition, page 3-59.



Trench Design Volumetric Flow	Q	3260 gpm	7.26 ft^3/s	
Channel Width	b	2 ft		
Roughness Factor for Unfinished Concrete [1]	n	0.015		
Slope of Trench [2]	S	0.002 Dh / unit L		
Flowing Liquid Depth in Channel	h	**1.221** ft	goal seek value	
Flowing Liquid Cross-Sectional Area	A	2.443 ft^2	*A = b * h*	
Hydraulic Radius of Trench	R_h	0.550	$R_h = \frac{bh}{2h+b}$	
Manning relation for Chézy coef.- open channel flow	C	89.67	$C = \frac{1.486}{n} R_h^{1/6}$	
Velocity	V1	2.97 ft/s	$V_1 = Q/A$	
Velocity	V2	2.97 ft/s	$V_2 = C\sqrt{R_h S}$	
	V1 - V2	0.0000	set to zero by varying h	
Design Trench Depth	D	2 ft TRENCH DEPTH OK		
Trench Freeboard	f	9.3 in	f = D - h	

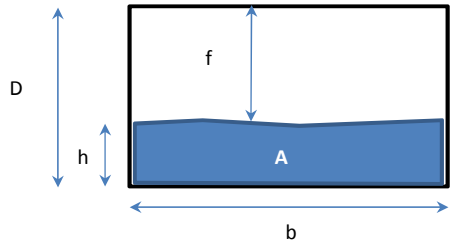
NOTES:
1. Roughness factor is conservative, as this value is based on water. Boiling LNG will have less frictional resistance.
2. 0.2% or 2 ft fall in 1,000 ft run.

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

CB&I		**Spill Impoundment Sizing & Thermal Radiation Calculations**		PSE PUGET SOUND ENERGY	
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:		**Client:**	Puget Sound Energy	**Sheet**	6 of 7
Office:	PSE	**Project:**	Tacoma LNG		

Process N-S Spill Trench Sizing (South of E-W pipe rack)

A concrete trench will be provided from the main pipe rack to the process area spill sump to convey the design spill to the sump. The design spill flow rate is based on the largest credible spill scenario in the Liquefaction Area.
The following open channel flow calculation is based on the method from Mark's Handbook, 11th Edition, page 3-59.



Trench Design Volumetric Flow	Q	2408.0 gpm	5.37 ft^3/s	
Channel Width	b	2 ft		
Roughness Factor for Unfinished Concrete [1]	n	0.015		
Slope of Trench [2]	S	0.002 Dh / unit L		
Flowing Liquid Depth in Channel	h	**0.971** ft	goal seek value	
Flowing Liquid Cross-Sectional Area	A	1.942 ft^2	*A = b * h*	
Hydraulic Radius of Trench	R_h	0.493	$R_h = \frac{bh}{2h+b}$	
Manning relation for Chézy coef.- open channel flow	C	88.04	$C = \frac{1.486}{n} R_h^{1/6}$	
Velocity	V1	2.76 ft/s	$V_1 = Q/A$	
Velocity	V2	2.76 ft/s	$V_2 = C\sqrt{R_h S}$	
	V1 - V2	0.0000	set to zero by varying h	
Design Trench Depth	D	1.5 ft TRENCH DEPTH OK		
Trench Freeboard	f	6.4 in	f = D - h	

NOTES:
1. Roughness factor is conservative, as this value is based on water. Boiling LNG will have less frictional resistance.
2. 0.2% or 2 ft fall in 1,000 ft run.

CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

		Spill Impoundment Sizing & Thermal Radiation Calculations			
Revision:	A			**Job No:**	186512
Date:	30-Apr-2015			**Doc No.**	186512-000-PR-CL-01005
Made By:	GCB			**Calc No.**	
Checked:	JG	**Client:**	Puget Sound Energy	**Sheet**	7 of 7
Office:	PSE	**Project:**	Tacoma LNG		

Determine minimum spacing between Process Sump and LNG Tank based on the maximum allowable thermal radiation heat flux (10,000 Btu/hr-ft^2) at varying target elevations on the tank wall during a sump fire.

LNGFIRE3 Input

Pool Diameter	22.25	ft	
Height of Flame Base	0.0	ft	
Height of Target	0.0	ft	Varied from 0 ft to 14 ft in results below
Wind Speed	15.6	mph	Design Basis (186512-000-PR-DB-00001)
Radiation Temp	31.95	°F	= Tavg[Dec] - MCDBR/2
Relative Humidity	57.2	%	ASHRAE 2013 Station Data - McChord AFB
MW	16.62	lb/lbmol	H&MB Stream #12
Density	27.32	lb/cuft	H&MB Stream #12
Fluid Temp.	198.57	°R	H&MB Stream #12

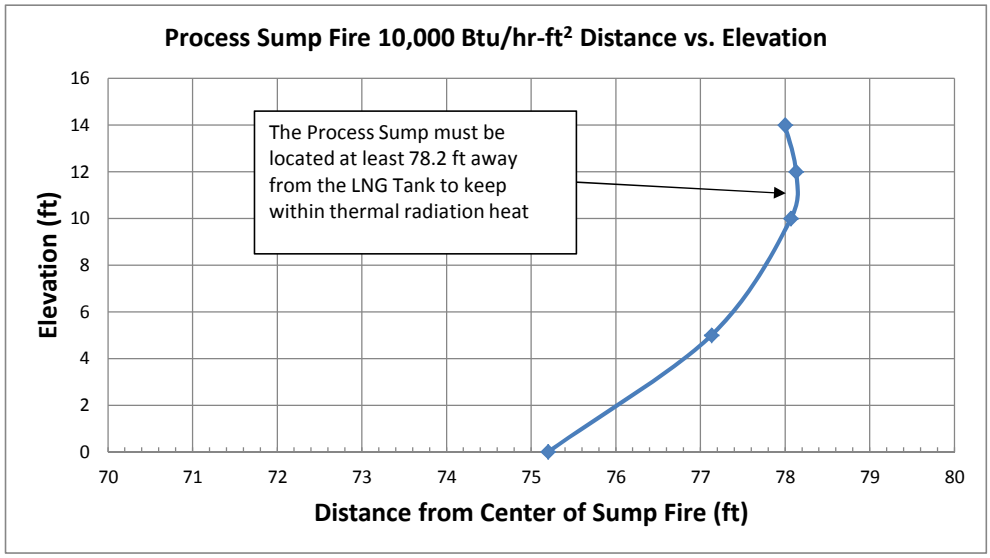
LNGFIRE3 Output

Sump Fire Thermal Radiation at Varying Elevation

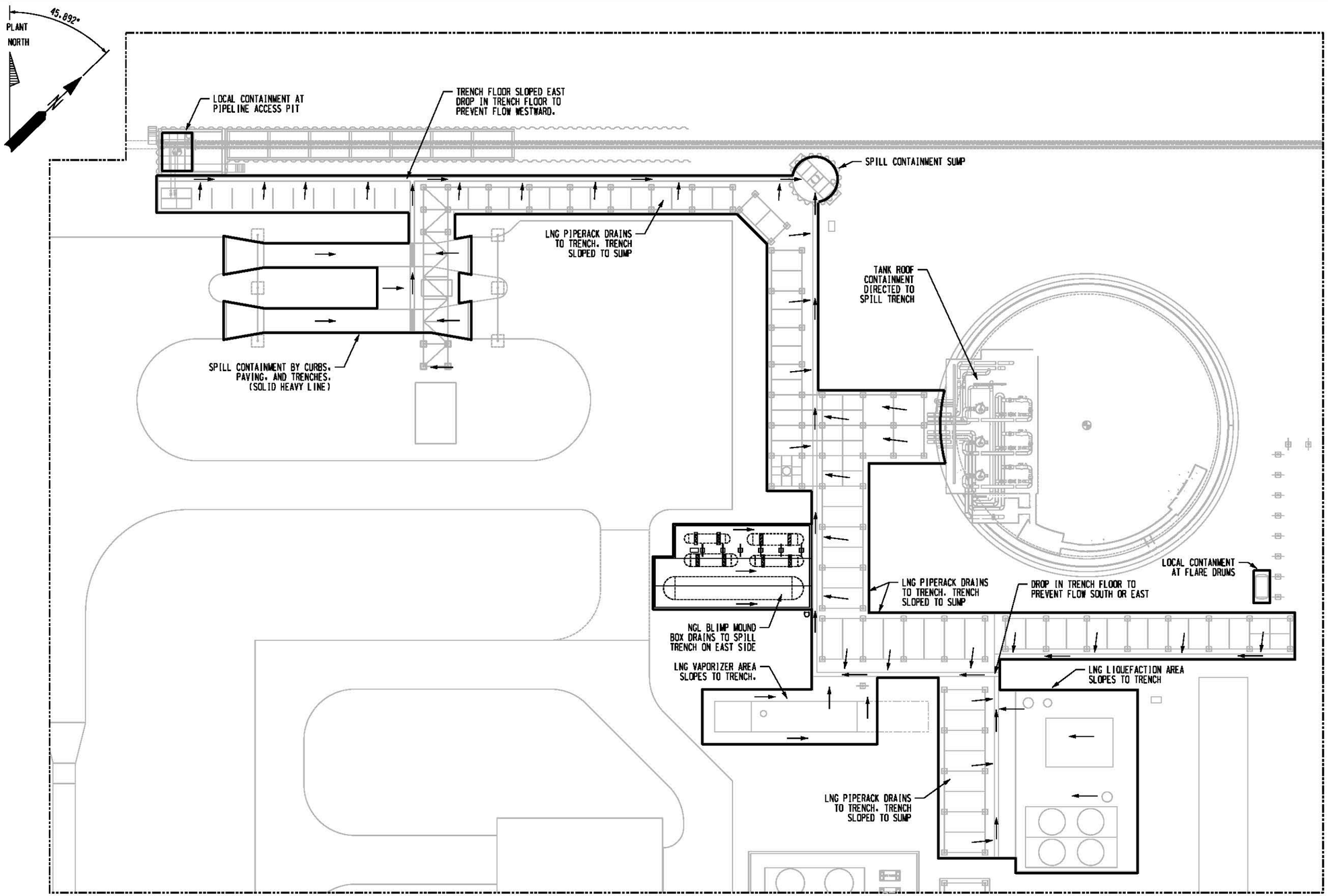
Target Elevation ft	Distance to Flux Level ft	Radiant Heat Flux BTU/hr-ft^2	
0	75.2	10000	
5	77.13	10000	
10	78.07	10000	
12	**78.13**	10000	**<-- Minimum distance required based on 12 ft receptor elevation**
14	78.00	10000	

Flame Length	56.28	ft
Flame Tile from Vertical	61.76	deg
Vertical Flame Height	26.63	ft

LNGFire cannot analyze above the elevation of the vertical flame length



APPENDIX G – SPILL CONTAINMENT PLAN DRAWINGS



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SCALE: FEET

CLIENT DRG NO: –

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
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	C	ISSUED PRELIMINARY	DAS	MES	MES	15JUL15
	B	ISSUED PRELIMINARY	DAS	MES	MES	29JUN15
	A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

SPILL CONTAINMENT PLAN MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DRG NO: 000-CV-08-000101 | REV: C

Form CHG-836-08-F16-Q1R0 CBI Rev 0.dwg

IDOCS FOLDER 14.4.4.4.3

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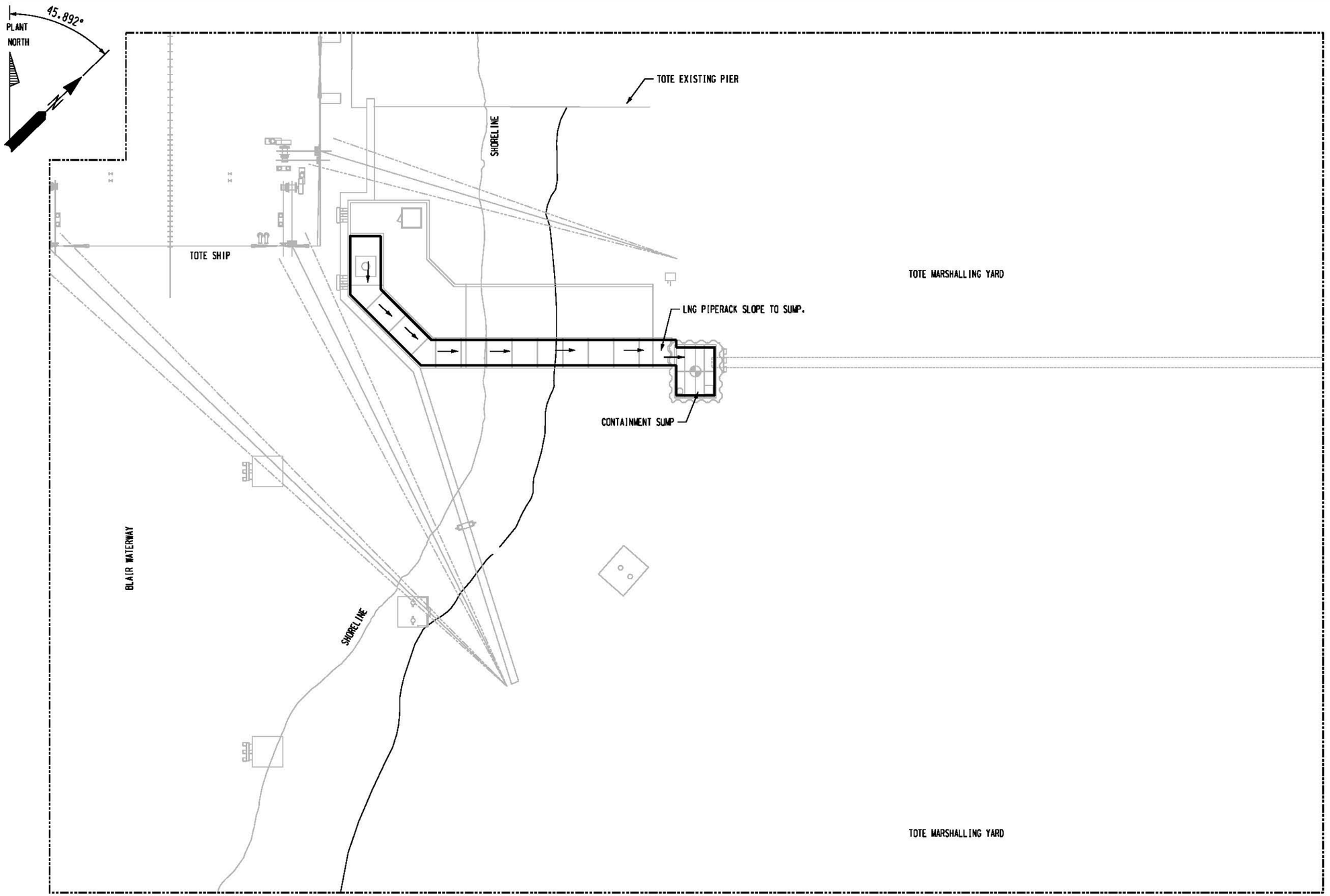

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CLIENT DRG NO: –

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	B	ISSUED PRELIMINARY	DAS	MES	MES	29JUN15
	A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

SPILL CONTAINMENT PLAN
BLAIR DOCK (TOTE)

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DRG NO: 000-CV-08-000102 | REV: B

Form CB&I-00-FM-00164 Ltr Mst R-dwg

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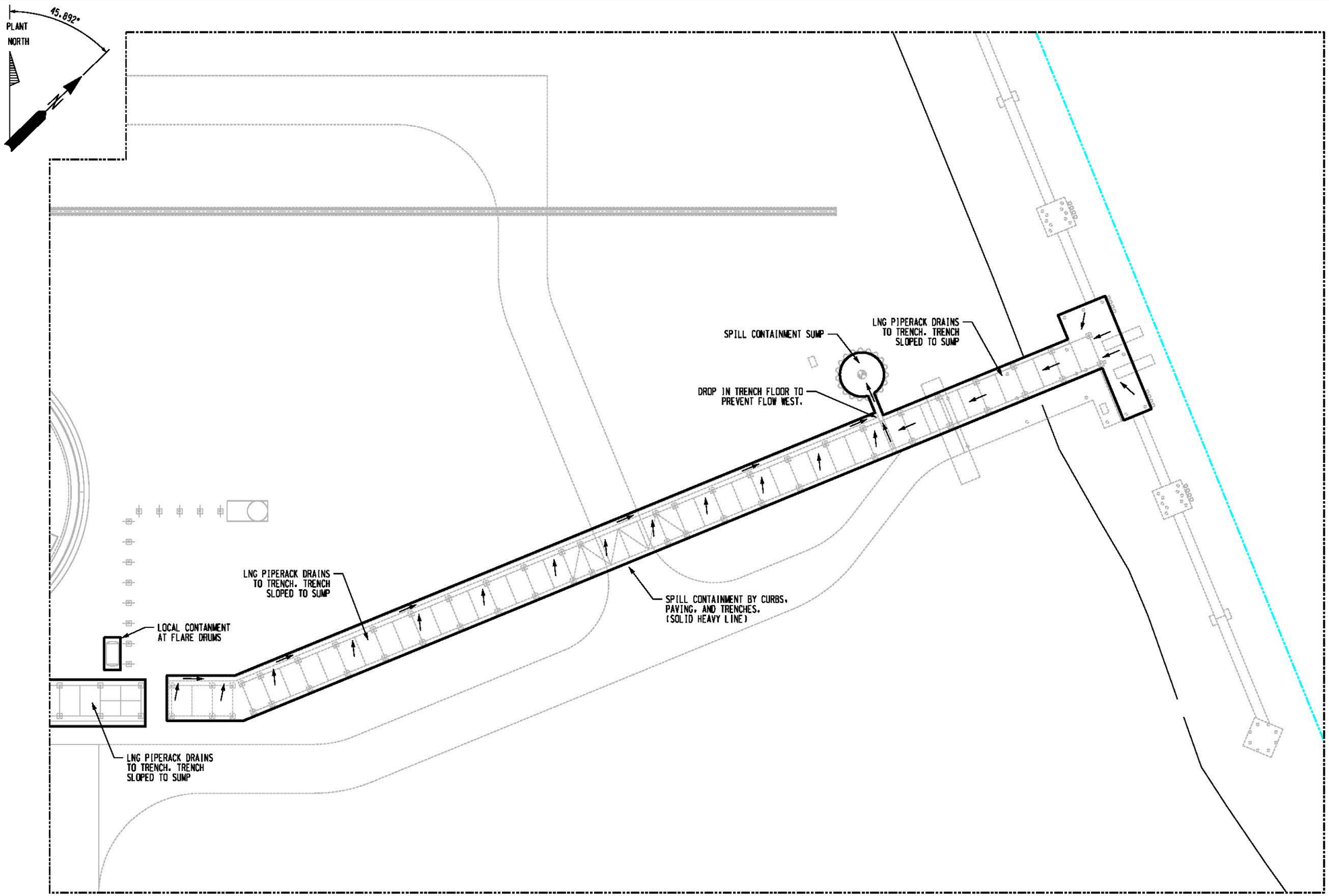

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CLIENT DRG NO: —

NOTES

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	B	ISSUED PRELIMINARY	DAS	MES	MES	29JUN15
	A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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SPILL CONTAINMENT PLAN HYLEBOS DOCK

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

PROJECT NO: 186512 | DRG NO: 000-CV-08-000103 | REV: C

Form CHE-635-08-F0-02164 CBI Mod B.dwg

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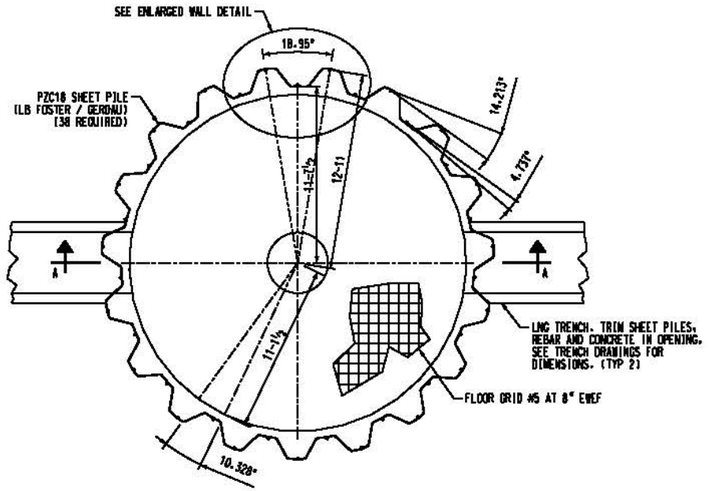
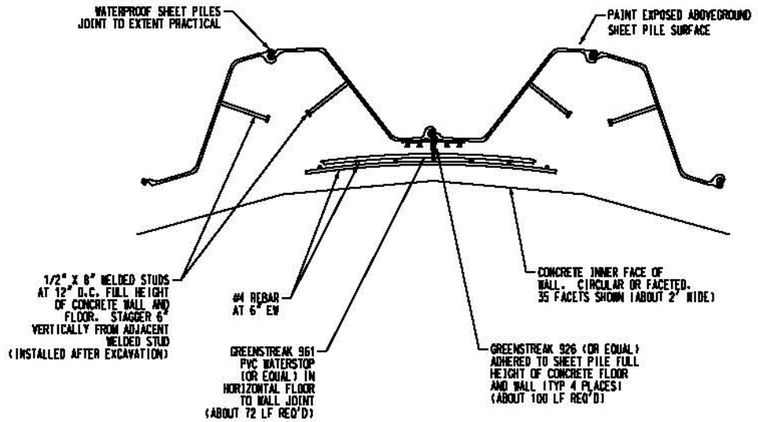
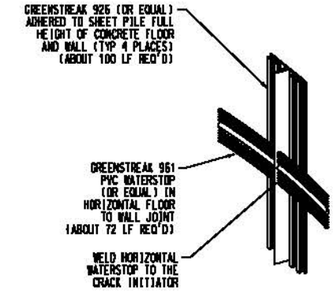
PLANT NORTH



IMPOUNDING SUMP PLAN



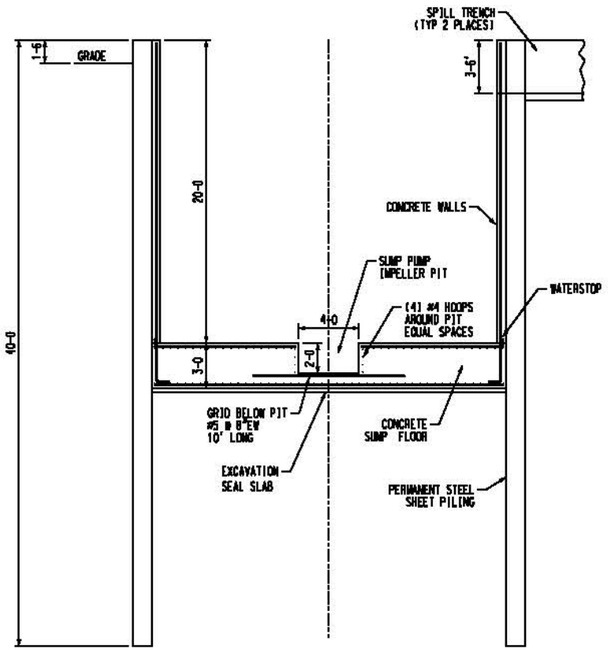
EXPANDED WALL DETAIL



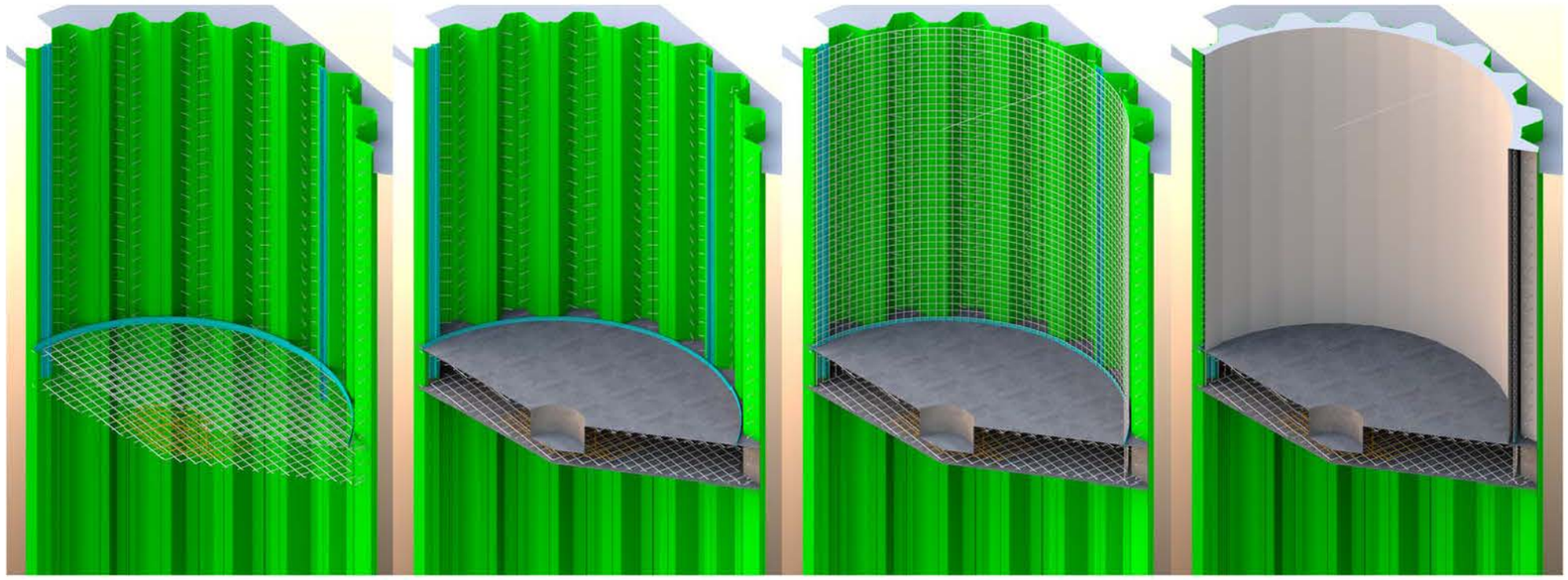
WATERSTOP JOINT DETAIL

APPROXIMATE MATERIAL TAKE OFF:

SHEET PILE STEEL:	79,700 LBS
SHEET PILE JOINTS:	1,520 FT
FLOOR REBAR:	2,900 LBS
WALL REBAR:	4,320 LBS
WELDED STUDS:	500 LBS
WATERSTOP:	172 FT
FLOOR CONCRETE:	52 CY
WALL CONCRETE:	68 CY



SECTION A-A



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DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 25MAR15 | SCALE: AS SHOWN

PROCESS SPILL SUMP PLAN

TACOMA LNG

TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-210001 | REV: A

H: / Project / 186512 / 05 Engineering / 05.13 Drawings / 05.13.03 Concrete / 186512-000-CV-08-210001.dgn 10docs folder 14.4.4.4.3

APPENDIX H – FIRE THERMAL RADIATION CALCULATIONS & EXCLUSION ZONE DRAWING

DOCUMENT NO.: 186512-000-SE-RP-00001	REVISION: C	

LNG TANK CONCRETE CONTAINMENT FIRE:

THERMAL RADIATION CALCULATIONS

LNGFIRE MODEL RESULTS: 135.5 FT DIAMETER CIRCULAR POOL

INPUT

MOLECULAR WEIGHT	16.62
LNG LIQUID DENSITY (LB/FT^3)	27.32
BOILING TEMPERATURE (R)	198.57
FLAME BASE HEIGHT (FT)	118.50
TARGET HEIGHT (FT)	0.00
POOL DIAMETER (FT)	135.50
WIND SPEED (MPH)	15.60
AMBIENT TEMPERATURE (F)	31.95
RELATIVE HUMIDITY (%)	54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)	0.02253
FLAME LENGTH (FT)	203.06
FLAME TILT FROM VERTICAL (DEG)	49.90
FLAME DRAG RATIO	1.00
EFF. EMISSIVE POWER (BTU/FT^2 HR)	60317.21

THERMAL FLUX (BTU/FT^2 HR)	FEDERAL CODE DISTANCE FROM CENTER OF POOL (FT)
10,000	223.08
6,700	259.32
4,000	363.59
1,600	550.24

DOCUMENT NO.: 186512-000-SE-RP-00001	REVISION: C	

PROCESS SPILL SUMP FIRE:

THERMAL RADIATION CALCULATIONS

LNGFIRE MODEL RESULTS: 22.25 FT DIAMETER CIRCULAR POOL

INPUT

MOLECULAR WEIGHT	16.62
LNG LIQUID DENSITY (LB/FT^3)	27.32
BOILING TEMPERATURE (R)	198.57
FLAME BASE HEIGHT (FT)	0.00
TARGET HEIGHT (FT)	0.00
POOL DIAMETER (FT)	22.25
WIND SPEED (MPH)	15.60
AMBIENT TEMPERATURE (F)	31.95
RELATIVE HUMIDITY (%)	54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)	0.02154
FLAME LENGTH (FT)	56.28
FLAME TILT FROM VERTICAL (DEG)	61.76
FLAME DRAG RATIO	1.47
EFF. EMISSIVE POWER (BTU/FT^2 HR)	57273.68

THERMAL FLUX (BTU/FT^2 HR)	FEDERAL CODE DISTANCE FROM CENTER OF POOL (FT)
10,000	75.24
6,700	84.42
4,000	97.04
1,600	125.66

LNGFIRE MODEL RESULTS: 22.25 FT DIAMETER CIRCULAR POOL

INPUT

MOLECULAR WEIGHT	16.62
LNG LIQUID DENSITY (LB/FT^3)	27.32
BOILING TEMPERATURE (R)	198.57
FLAME BASE HEIGHT (FT)	0.00
TARGET HEIGHT (FT)	0.00
POOL DIAMETER (FT)	22.25
WIND SPEED (MPH)	15.60
AMBIENT TEMPERATURE (F)	31.95
RELATIVE HUMIDITY (%)	54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)	0.02154
FLAME LENGTH (FT)	56.28
FLAME TILT FROM VERTICAL (DEG)	61.76
FLAME DRAG RATIO	1.47
EFF. EMISSIVE POWER (BTU/FT^2 HR)	57273.68

	THERMAL FLUX TO:		
DISTANCE FROM CENTER OF POOL (FT)	HORIZONTAL TARGET (BTU/FT^2 HR)	VERTICAL TARGET (BTU/FT^2 HR)	MAXIMUM FLUX TO TARGET (BTU/FT^2 HR)
100.00	1231	3363	3581
101.00	1163	3251	3453
102.00	1099	3144	3330
103.00	1039	3041	3214
104.00	984	2943	3103
105.00	932	2849	2997
106.00	883	2758	2896
107.00	838	2672	2800
108.00	795	2589	2708
109.00	755	2509	2620

LNGFIRE MODEL RESULTS: 22.25 FT DIAMETER CIRCULAR POOL

INPUT

MOLECULAR WEIGHT	16.62
LNG LIQUID DENSITY (LB/FT^3)	27.32
BOILING TEMPERATURE (R)	198.57
FLAME BASE HEIGHT (FT)	0.00
TARGET HEIGHT (FT)	10.00
POOL DIAMETER (FT)	22.25
WIND SPEED (MPH)	15.60
AMBIENT TEMPERATURE (F)	31.95
RELATIVE HUMIDITY (%)	54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)	0.02154
FLAME LENGTH (FT)	56.28
FLAME TILT FROM VERTICAL (DEG)	61.76
FLAME DRAG RATIO	1.47
EFF. EMISSIVE POWER (BTU/FT^2 HR)	57273.68

THERMAL FLUX (BTU/FT^2 HR)	FEDERAL CODE DISTANCE FROM CENTER OF POOL (FT)
10,000	78.07
6,700	84.89
4,000	95.25
1,600	121.10

LNGFIRE MODEL RESULTS: 22.25 FT DIAMETER CIRCULAR POOL

INPUT

MOLECULAR WEIGHT	16.62
LNG LIQUID DENSITY (LB/FT^3)	27.32
BOILING TEMPERATURE (R)	198.57
FLAME BASE HEIGHT (FT)	0.00
TARGET HEIGHT (FT)	12.00
POOL DIAMETER (FT)	22.25
WIND SPEED (MPH)	15.60
AMBIENT TEMPERATURE (F)	31.95
RELATIVE HUMIDITY (%)	54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)	0.02154
FLAME LENGTH (FT)	56.28
FLAME TILT FROM VERTICAL (DEG)	61.76
FLAME DRAG RATIO	1.47
EFF. EMISSIVE POWER (BTU/FT^2 HR)	57273.68

THERMAL FLUX (BTU/FT^2 HR)	FEDERAL CODE DISTANCE FROM CENTER OF POOL (FT)
10,000	78.13
6,700	84.58
4,000	94.49
1,600	119.83

LNGFIRE MODEL RESULTS: 22.25 FT DIAMETER CIRCULAR POOL

INPUT

MOLECULAR WEIGHT	16.62
LNG LIQUID DENSITY (LB/FT^3)	27.32
BOILING TEMPERATURE (R)	198.57
FLAME BASE HEIGHT (FT)	0.00
TARGET HEIGHT (FT)	14.00
POOL DIAMETER (FT)	22.25
WIND SPEED (MPH)	15.60
AMBIENT TEMPERATURE (F)	31.95
RELATIVE HUMIDITY (%)	54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)	0.02154
FLAME LENGTH (FT)	56.28
FLAME TILT FROM VERTICAL (DEG)	61.76
FLAME DRAG RATIO	1.47
EFF. EMISSIVE POWER (BTU/FT^2 HR)	57273.68

THERMAL FLUX (BTU/FT^2 HR)	FEDERAL CODE DISTANCE FROM CENTER OF POOL (FT)
10,000	78.05
6,700	84.02
4,000	93.54
1,600	118.39

DOCUMENT NO.: 186512-000-SE-RP-00001	REVISION: C	

TOTE TRANSITION PIT FIRE:

THERMAL RADIATION CALCULATIONS

LNGFIRE MODEL RESULTS: 14 X 18.86 FT RECTANGULAR POOL

INPUT

MOLECULAR WEIGHT		16.62
LNG LIQUID DENSITY (LB/FT^3)		27.32
BOILING TEMPERATURE (R)		198.57
FLAME BASE HEIGHT (FT)		0.00
TARGET HEIGHT (FT)		0.00
POOL WIDTH (FT)		14.00
POOL LENGTH (FT)		18.86
WIND SPEED (MPH)		15.60
AMBIENT TEMPERATURE (F)		31.95
RELATIVE HUMIDITY (%)		54.70

OUTPUT

MASS BURNING RATE (LB/FT^2 S)		0.02253
FLAME LENGTH (FT)		41.93
FLAME TILT FROM VERTICAL (DEG)	(FRONT)	63.82
	(SIDE)	62.37
FLAME DRAG RATIO	(FRONT)	1.91
	(SIDE)	1.71
EFF. EMISSIVE POWER (BTU/FT^2 HR)	(FRONT)	55073.76
	(SIDE)	57152.41

FRONT VIEW	
THERMAL FLUX (BTU/FT^2 HR)	FEDERAL CODE DISTANCE FROM CENTER OF POOL (FT)
10,000	68.75
6,700	75.27
4,000	84.65
1,600	106.66
SIDE VIEW	
10,000	68.00
6,700	74.08
4,000	83.21
1,600	103.48

LNGFIRE MODEL RESULTS: 14 X 18.86 FT RECTANGULAR POOL

INPUT

MOLECULAR WEIGHT		16.62
LNG LIQUID DENSITY (LB/FT^3)		27.32
BOILING TEMPERATURE (R)		198.57
FLAME BASE HEIGHT (FT)		0.00
TARGET HEIGHT (FT)		0.00
POOL WIDTH (FT)		14.00
POOL LENGTH (FT)		18.86
WIND SPEED (MPH)		15.60
AMBIENT TEMPERATURE (F)		31.95
RELATIVE HUMIDITY (%)		54.70

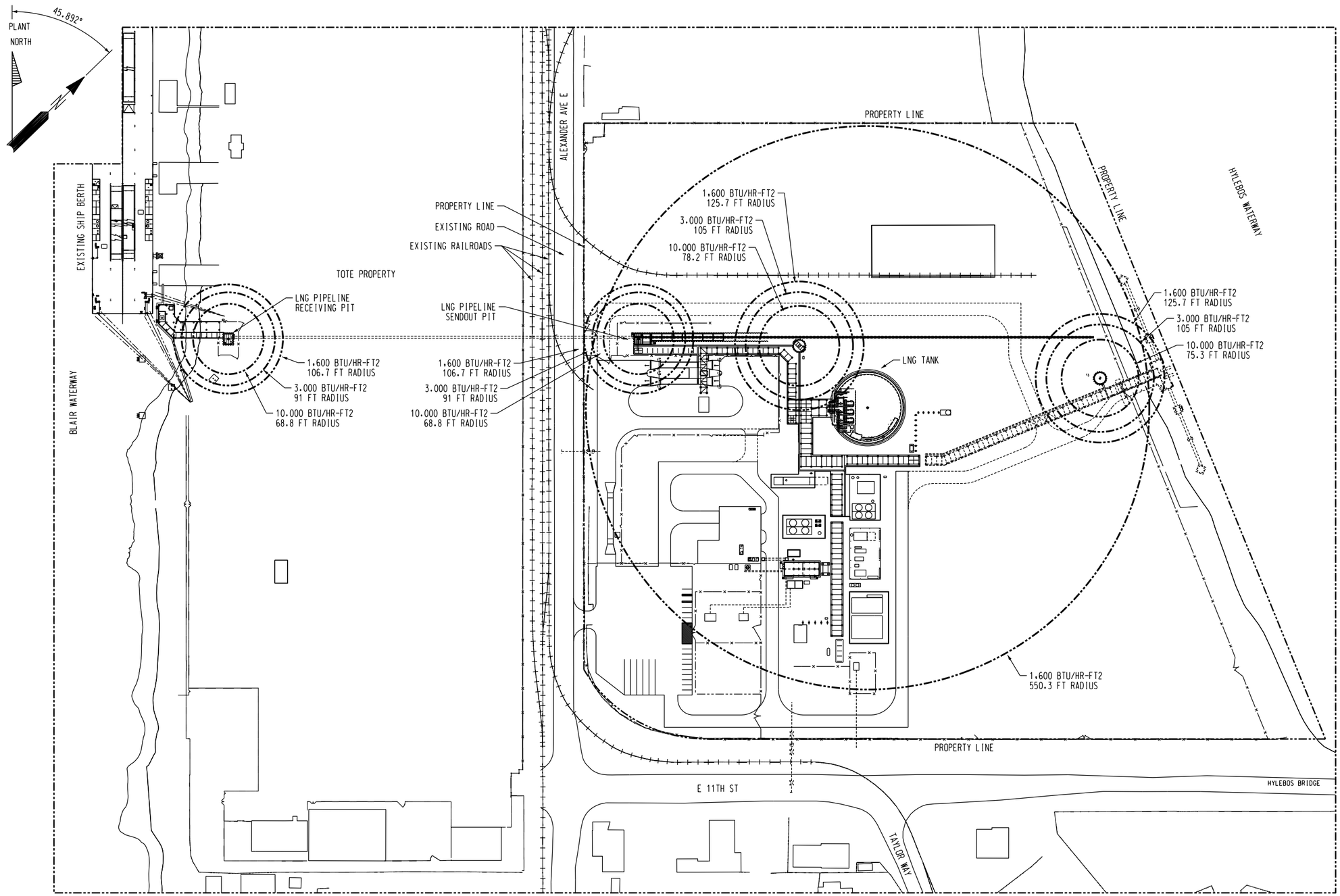
OUTPUT

MASS BURNING RATE (LB/FT^2 S)		0.02253
FLAME LENGTH (FT)		41.93
FLAME TILT FROM VERTICAL (DEG)	(FRONT)	63.82
	(SIDE)	62.37
FLAME DRAG RATIO	(FRONT)	1.91
	(SIDE)	1.71
EFF. EMISSIVE POWER (BTU/FT^2 HR)	(FRONT)	55073.76
	(SIDE)	57152.41

FRONT VIEW	THERMAL FLUX TO:		
DISTANCE FROM CENTER OF POOL (FT)	HORIZONTAL TARGET (BTU/FT^2 HR)	VERTICAL TARGET (BTU/FT^2 HR)	MAXIMUM FLUX TO TARGET (BTU/FT^2 HR)
85.00	1253	3729	3934
86.00	1160	3559	3743
87.00	1074	3398	3564
88.00	997	3247	3396
89.00	926	3105	3239
90.00	861	2971	3093
91.00	802	2844	2955
92.00	748	2725	2826
93.00	699	2613	2705
94.00	653	2507	2590
SIDE VIEW			
85.00	1292	3396	3633
86.00	1192	3237	3449
87.00	1101	3087	3277
88.00	1019	2946	3117
89.00	944	2813	2967
90.00	876	2688	2827
91.00	814	2570	2696
92.00	757	2459	2573
93.00	705	2355	2458
94.00	657	2256	2350

THERMAL RADIATION EXCLUSION ZONE DRAWING

186512-000-SE-01-000011	Rev. D	Thermal Exclusion Zone Plan – Main LNG Plant with Blair Dock (TOTE) and Hylebos Dock



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SCALE: FEET

CLIENT DWG NO: —

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

REFERENCE DRAWINGS	NO.	REVISION	DRAWN	CK'D	APPD	DATE
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	-	-	-	-	-	-
	D	ISSUED PRELIMINARY	DAS	MES	MES	15JUL15
	C	ISSUED PRELIMINARY	DAS	GCB	MES	16JUN15
	B	ISSUED PRELIMINARY	DAS	GCB	MES	22APR15
	A	ISSUED PRELIMINARY	DAS	GCB	MES	13APR15

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THERMAL EXCLUSION ZONE PLAN - MAIN LNG PLANT WITH BLAIR DOCK AND HYLEBOS DOCK

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

DRAWN: DAS | CK'D: GCB | APPD: MES | DATE: 13APR15 | SCALE: AS SHOWN

PROJECT NO: 186512 | DWG NO: 000-SE-01-000011 | REV: D

Form CMS-830-00-FM-02104 CB1 ANSI D.dwg

IDOCS FOLDER 14.9

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APPENDIX I – LNG RELEASES – SPILL SCENARIO CASE SUMMARY & LOCATIONS

Spill Scenario Summaries for FLACS

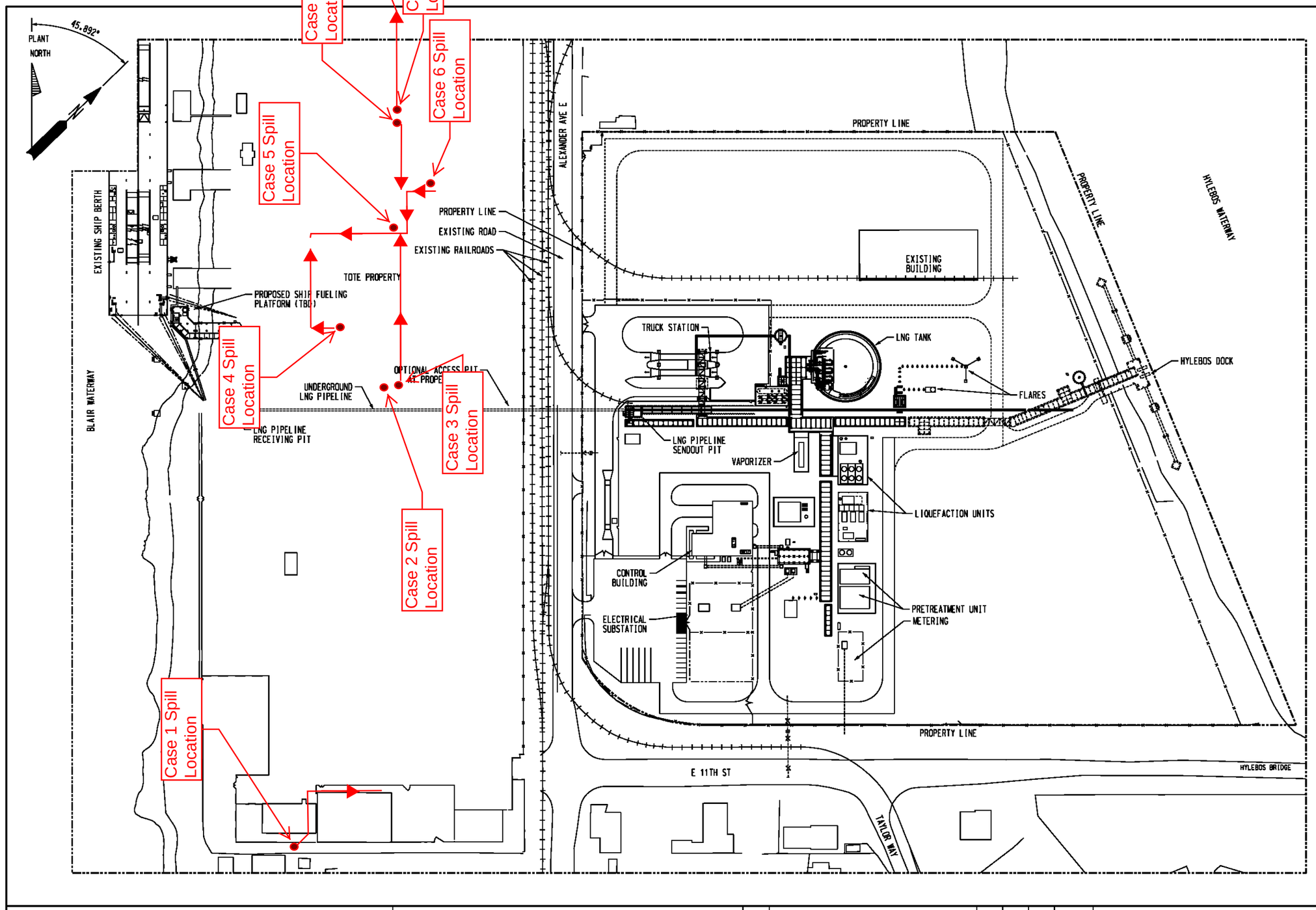
Revision:	A				**Job No:**	186512
Date:	20-Apr-2015				**Doc No.**	186512-000-PR-CL-05001
Made By:	JG		**Client:**	Puget Sound Energy	**Calc No.**	
Checked:	GCB		**Project:**	Tacoma LNG	**Sheet**	1 of 1
Office:	PSE		**Location:**	Tacoma, WA		

Case Study Properties and Spill Rate

	Case 1 - LNG Pipe Rupture at Tote Bunkering (TOTE dock side)	*Case 2 & 3- LNG Pipe Rupture to Tote Bunkering (facility side)*	*Case 4 - LNG Pipe Rupture at Truck Loading*	*Case 5 - Sendout Header Pipe Rupture at Grade*	*Case 6 - Refrigerated LNG Rundown Line to Tank Catastropic Rupture*	*Case 7, 8 &9 - LNG Pipe Rupture at HYLEBOS (Future)*
Liquid Fraction	1.0	1.0	1.0	1.0	1.0	1.0
Temperature (°F)	-258.5	-258.7	-258.7	-258.7	-255.0	-259.0
Pressure (psia)	98.5	114.5	118.5	118.5	18.8	18.2
Line Break Size (in)	3.33	3.33	1.00	3.33	3.00	8.00
Spill Rate (lb/hr)	598,161	665,710	61,123	665,710	49,988	711,003
Piping Item No.	137	109	110	107	25	113

NOTES

1. Average annual temperature, 50.9°F.
2. Spill locations are denoted on attached Site Plan
3. Tank coordinates are approximately N 47.2768 W 122.4004



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SCALE: FEET

CLIENT DWG NO: —

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CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

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	B	ISSUED FOR ESTIMATE	DAS	MES	MES	12MAR15
	A	ISSUED FOR REVIEW	DAS	MES	MES	24FEB15

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SITE PLAN – MAIN LNG PLANT WITH BLAIR DOCK AND HYLEBOS DOCK

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

DRAWN: DAS	CK'D: MES	APP'D: MES	DATE: 24FEB15	SCALE: AS SHOWN

PROJECT NO: 186512 | DWG NO: 000-CV-01-000003 | REV: B

Form CBI-036-DR-FR-02164 CBI MST 8.dwg

IDOCS FOLDER 14.4.4.1

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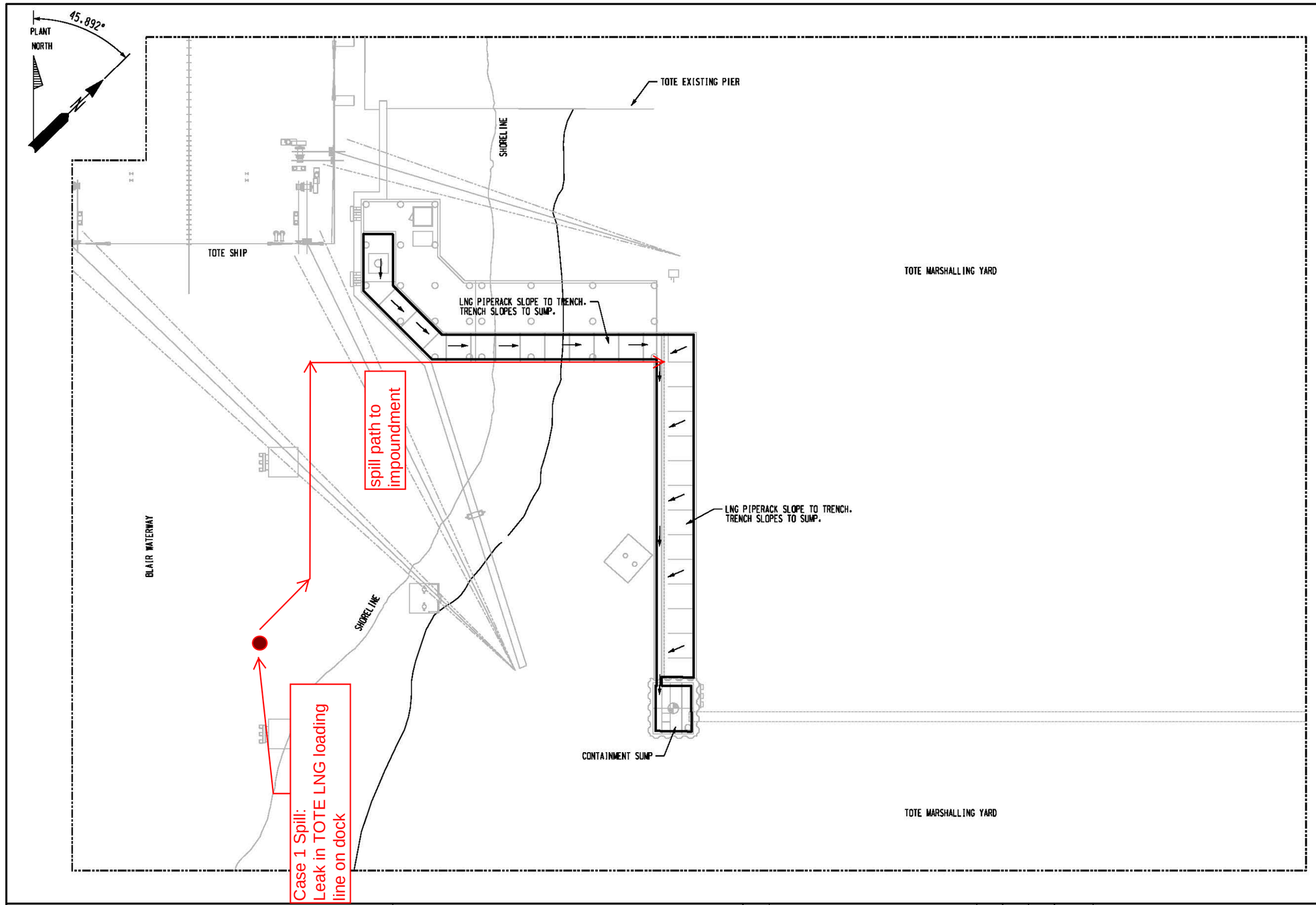

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SCALE: FEET

CLIENT DRG NO: –

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

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	A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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SPILL CONTAINMENT PLAN
BLAIR DOCK (TOTE)

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

DRAWN: DAS	CK'D: MES	APPD: MES	DATE: 21APR15	SCALE: AS SHOWN

PROJECT NO: 186512 | DRG NO: 000-CV-08-000102 | REV: A

Form CB&I-000-08-F0-02000 CBI MAST R-dwg

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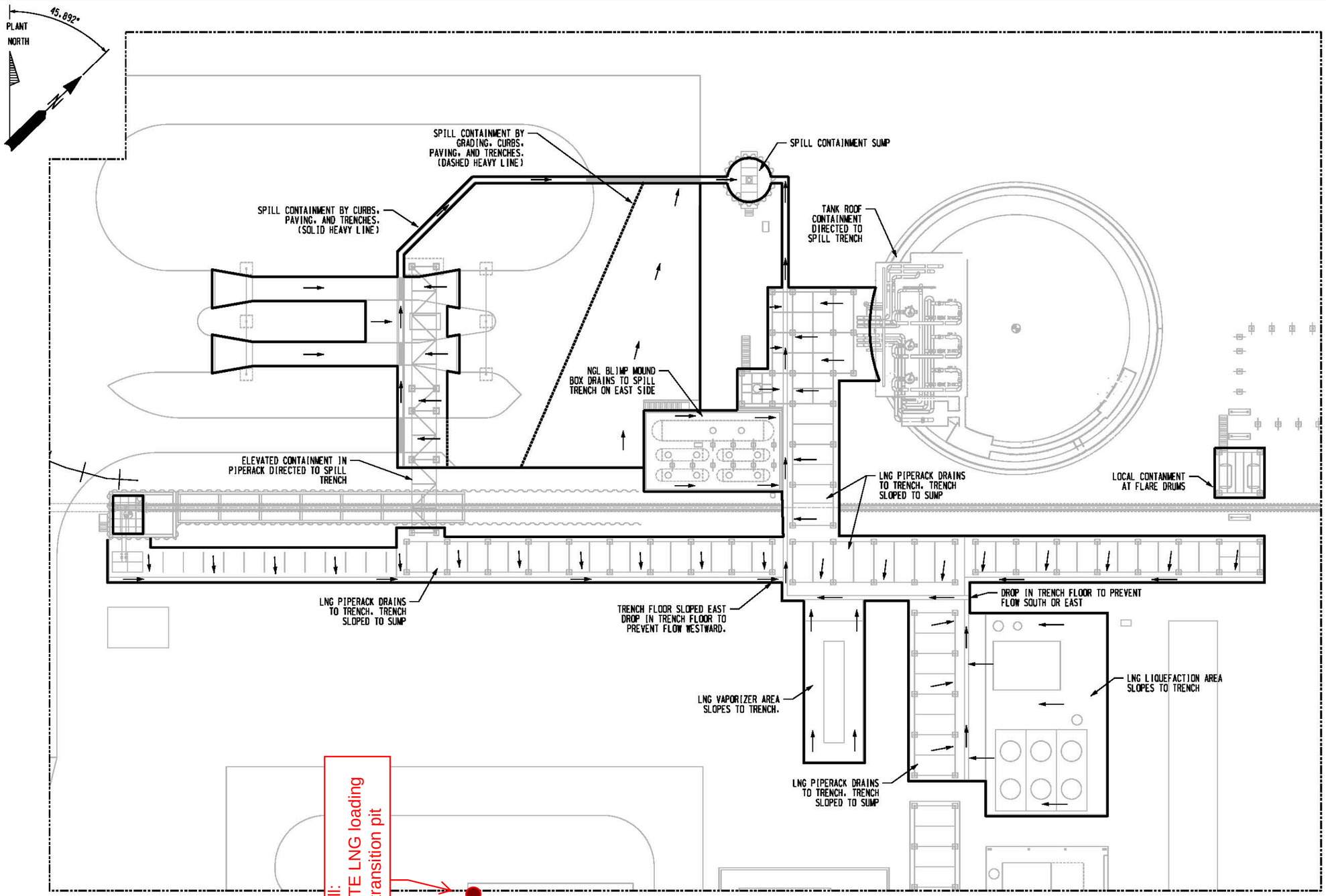

0 25 50 75 100 125

SCALE: FEET

CLIENT DRG NO: –

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

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	A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

SPILL CONTAINMENT PLAN MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000101 | REV: A

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!DOCS FOLDER 14.4.4.4.3

PLANT NORTH

45.892°

SPILL CONTAINMENT BY GRADING, CURBS, PAVING, AND TRENCHES. (DASHED HEAVY LINE)

SPILL CONTAINMENT BY CURBS, PAVING, AND TRENCHES. (SOLID HEAVY LINE)

SPILL CONTAINMENT SUMP

TANK ROOF CONTAINMENT DIRECTED TO SPILL TRENCH

NGL BLIMP MOUND BOX DRAINS TO SPILL TRENCH ON EAST SIDE

ELEVATED CONTAINMENT IN PIPERACK DIRECTED TO SPILL TRENCH

LNG PIPERACK DRAINS TO TRENCH. TRENCH SLOPED TO SUMP

LNG PIPERACK DRAINS TO TRENCH. TRENCH SLOPED TO SUMP

LOCAL CONTAINMENT AT FLARE DRUMS

spill path to impoundment

TRENCH FLOOR SLOPED EAST DROP IN TRENCH FLOOR TO PREVENT FLOW WESTWARD.

DROP IN TRENCH FLOOR TO PREVENT FLOW SOUTH OR EAST

LNG VAPORIZER AREA SLOPES TO TRENCH.

LNG LIQUEFACTION AREA SLOPES TO TRENCH

LNG PIPERACK DRAINS TO TRENCH. TRENCH SLOPED TO SUMP

Case 3 Spill:
Leak in TOTE LNG loading line at end of pipe rack

0 25 50 75 100 125

SCALE: FEET

CLIENT DRG NO: –

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

REFERENCE DRAWINGS

NO.	REVISION	DRAWN	CK'D	APPD	DATE
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A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

SPILL CONTAINMENT PLAN MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000101 | REV: A

Form CBI-635-08-F15-CBIWH CBI MKT R-dwg

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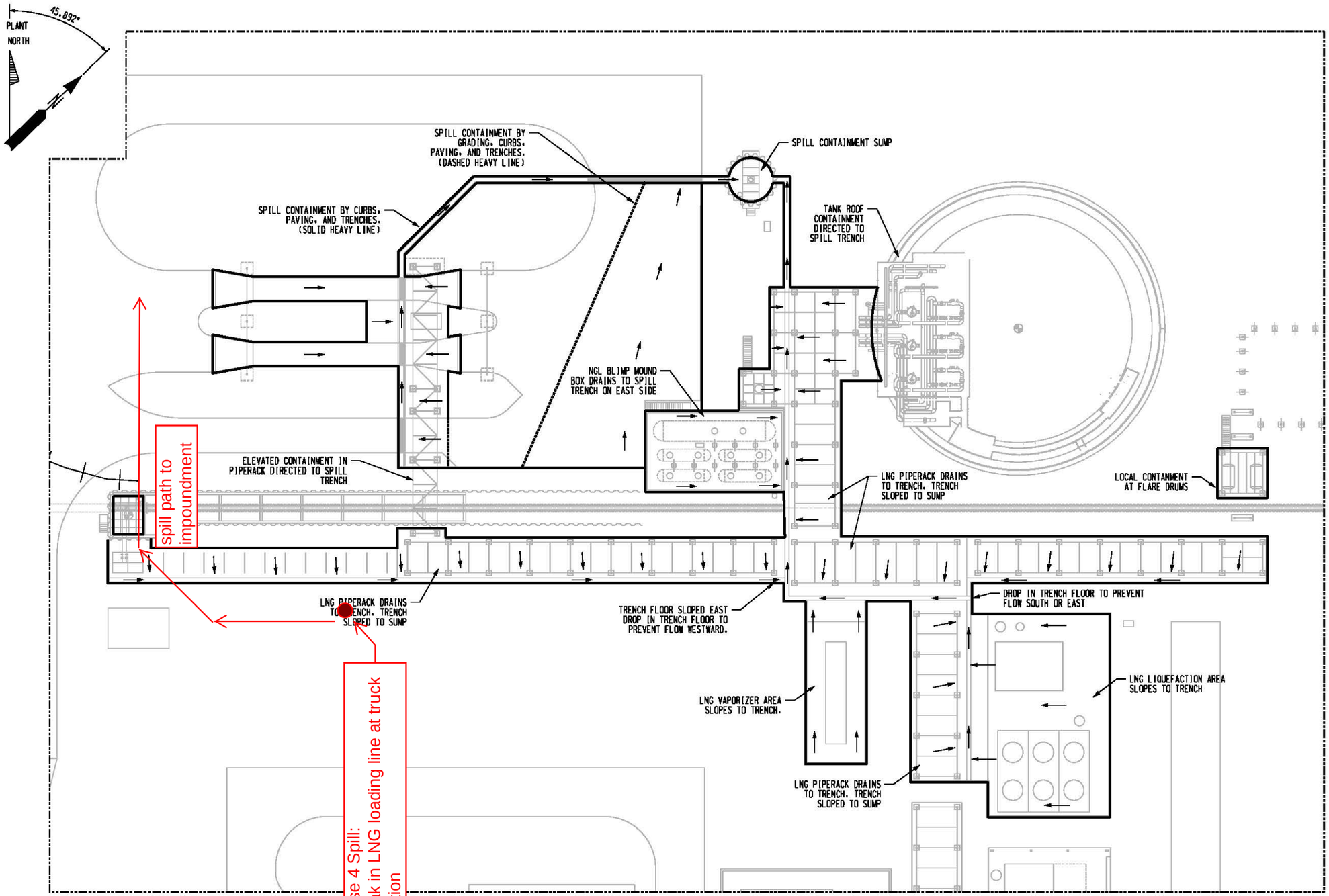

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SCALE: FEET

CLIENT DRG NO: —

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

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A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

REFERENCE DRAWINGS

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SPILL CONTAINMENT PLAN MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

PROJECT NO: 186512 | DRG NO: 000-CV-08-000101 | REV: A

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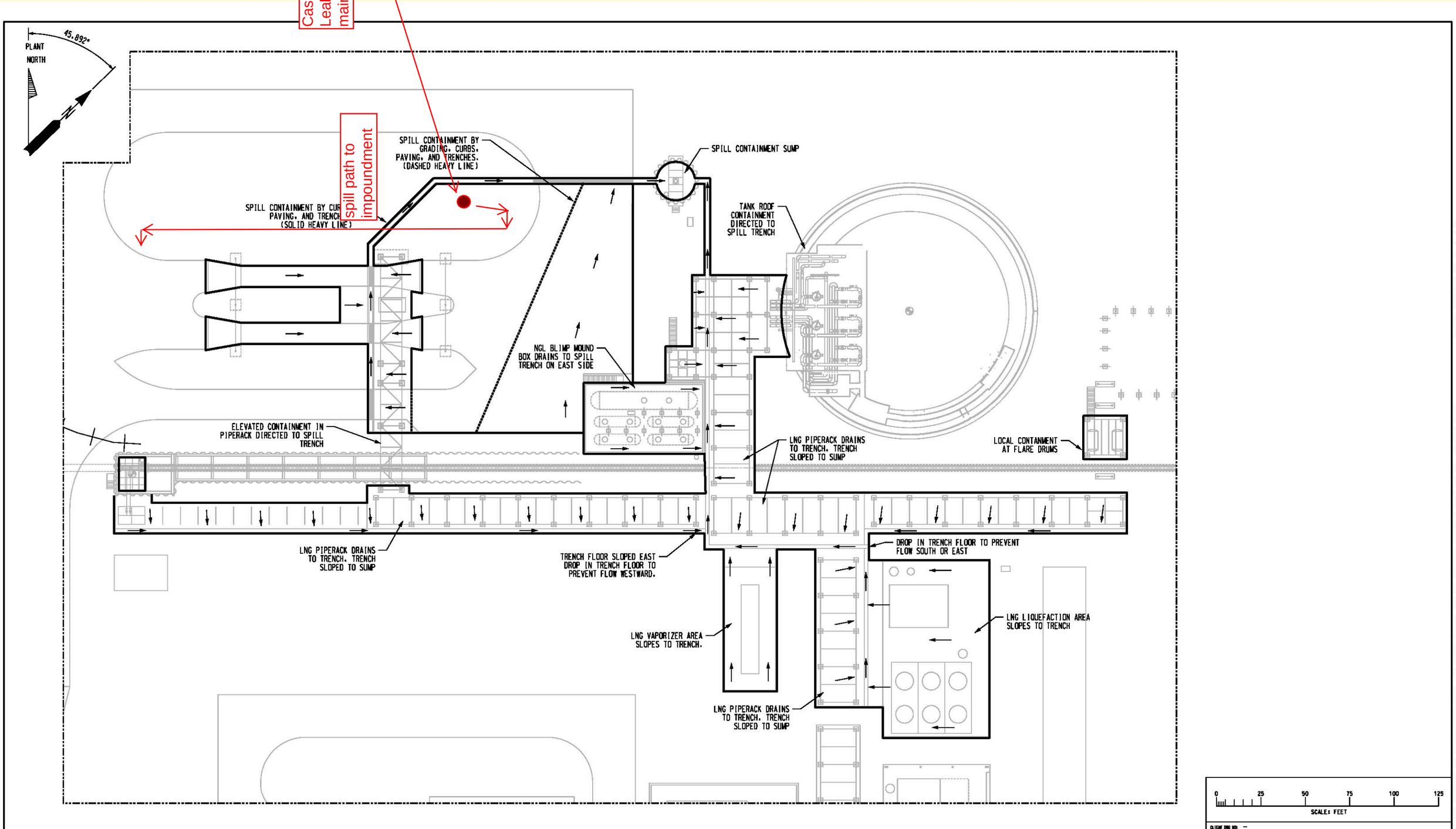

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SCALE: FEET

CLIENT DWG NO: —

NOTES

CONTAINS CRITICAL ENERGY INFRASTRUCTURE INFORMATION
DO NOT RELEASE

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A	ISSUED PRELIMINARY	DAS	MES	MES	21APR15

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CB&I

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DRAWN: DAS | CK'D: MES | APPD: MES | DATE: 21APR15 | SCALE: AS SHOWN

SPILL CONTAINMENT PLAN
MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000101 | REV: A

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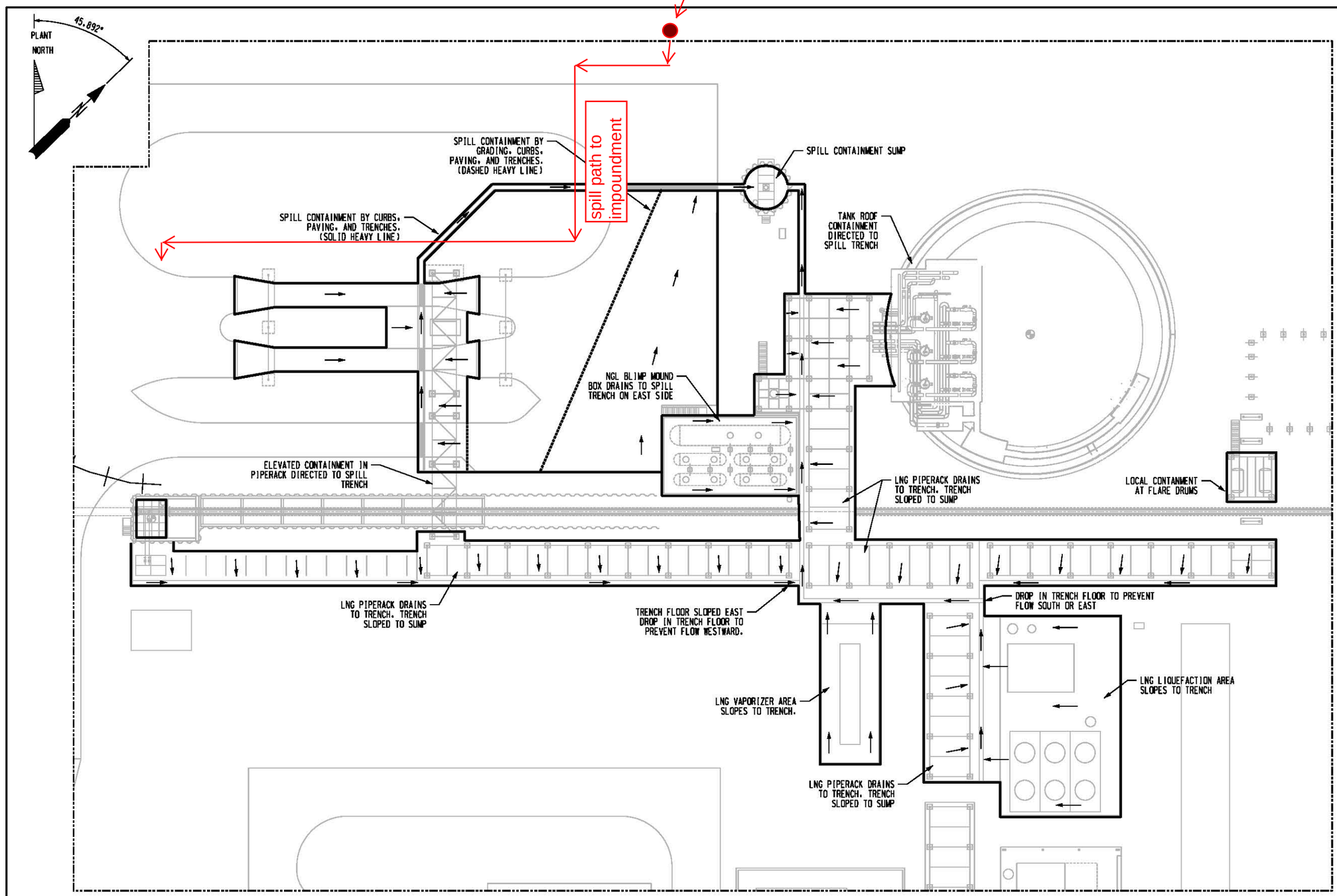

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SPILL CONTAINMENT PLAN MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000101 | REV: A

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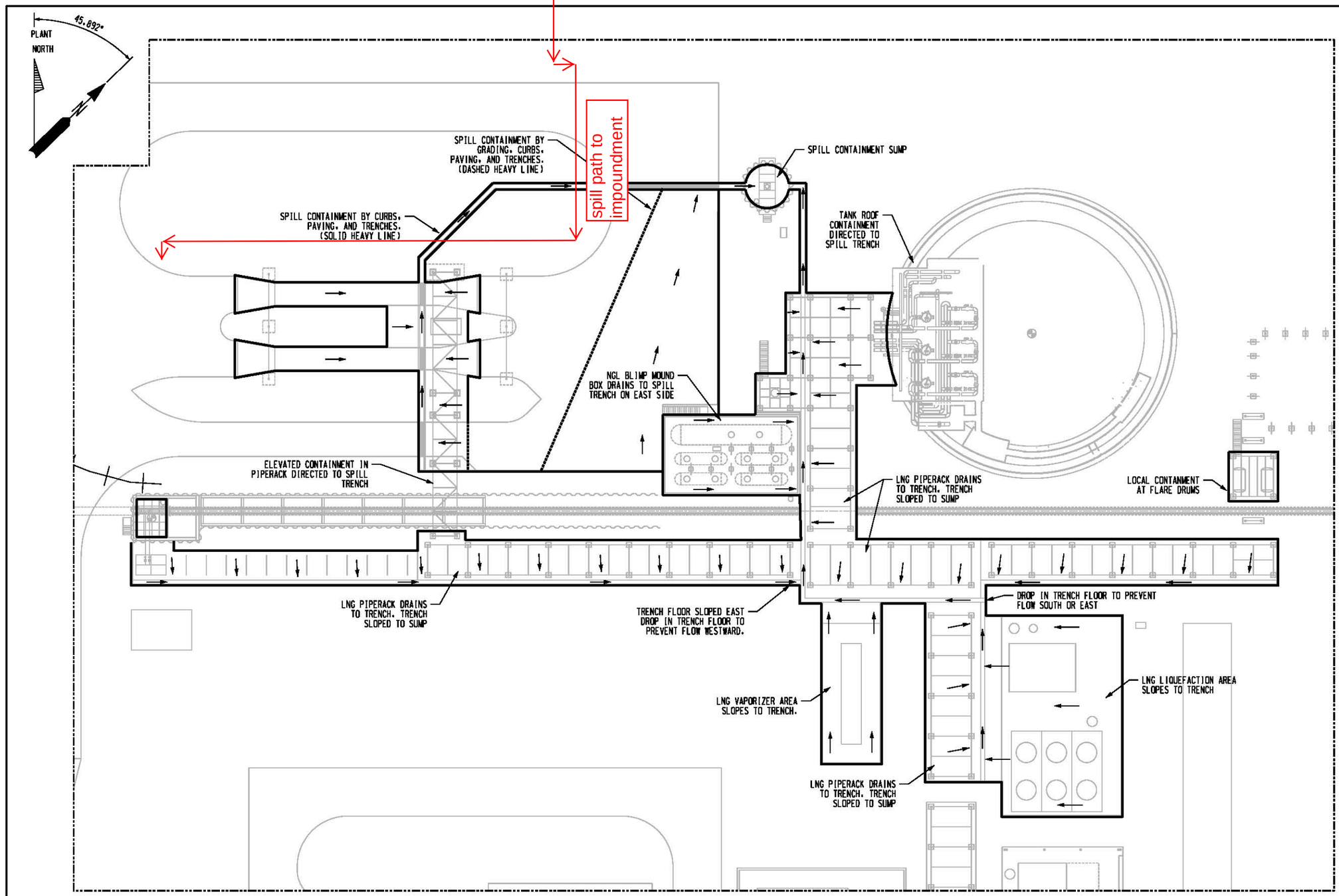

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SPILL CONTAINMENT PLAN MAIN LNG PLANT

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000101 | REV: A

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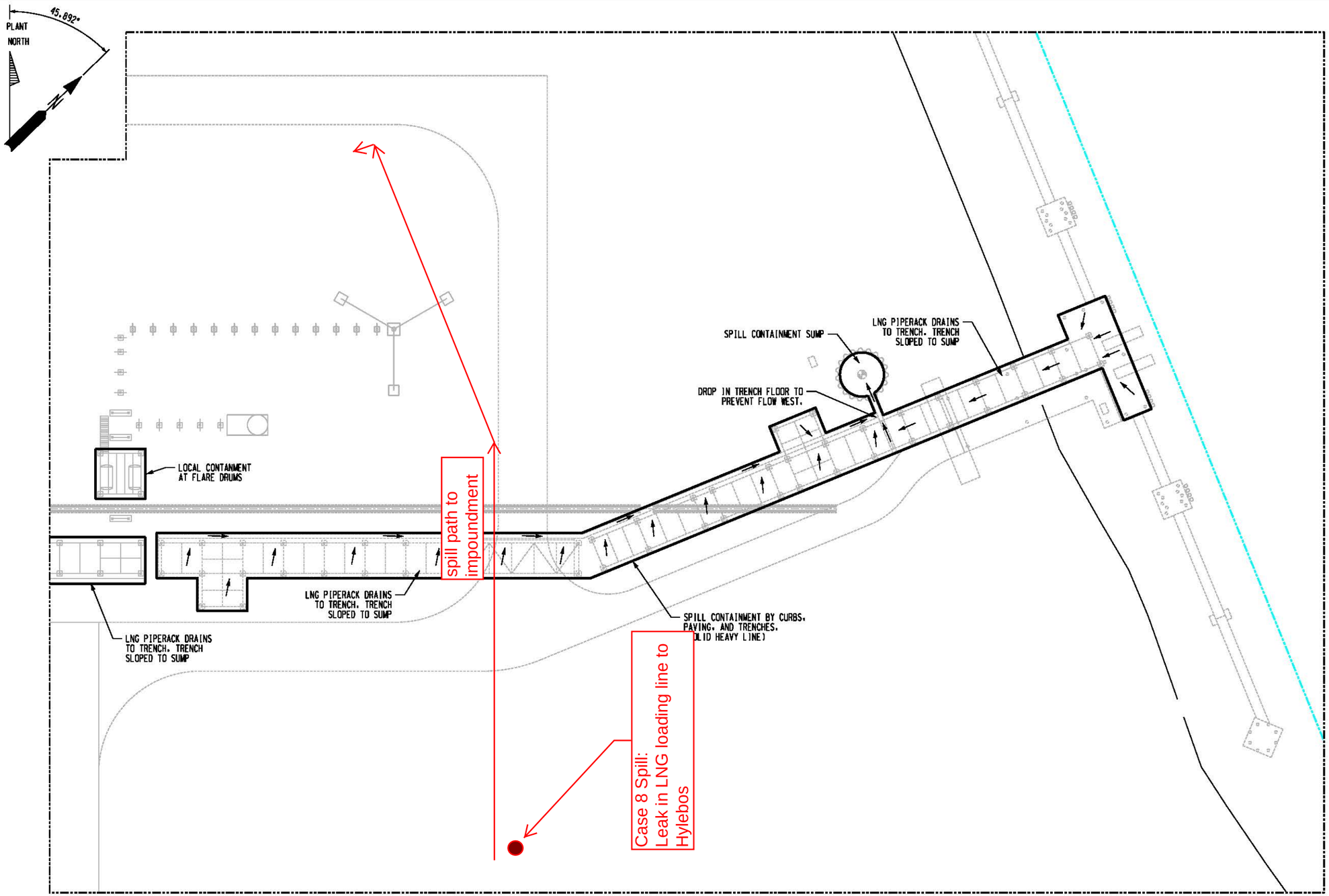

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SPILL CONTAINMENT PLAN
HYLEBOS DOCK

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000103 | REV: A

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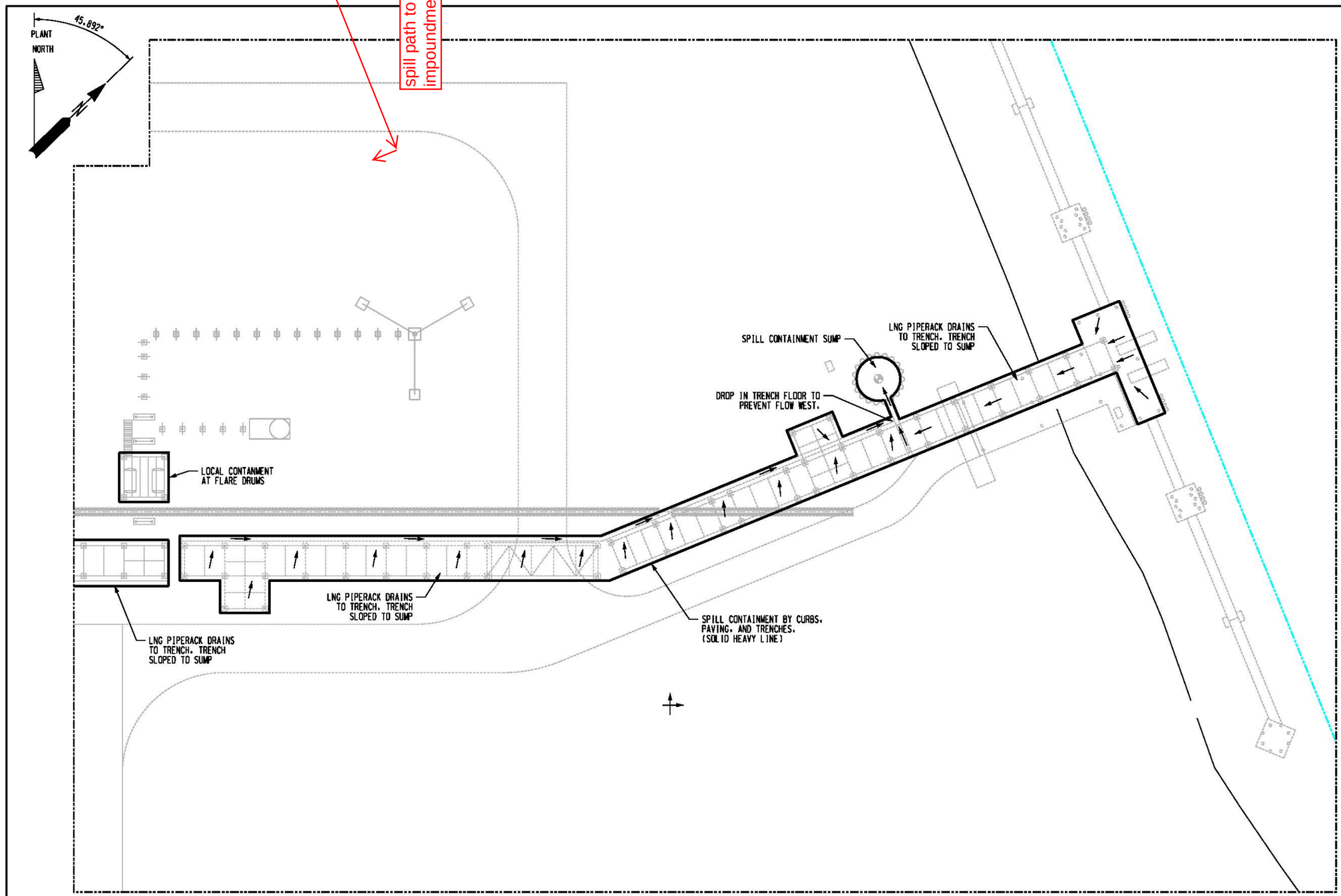

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SPILL CONTAINMENT PLAN HYLEBOS DOCK

TACOMA LNG
TACOMA, WA

FOR: PUGET SOUND ENERGY

PROJECT NO: 186512 | DWG NO: 000-CV-08-000103 | REV: A

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September 17, 2015

Matt Stobart
Chicago Bridge & Iron
14105 S. Route 59
Plainfield, IL 60544-8984

Subject: Flammable Gas Dispersion Analysis for the Tacoma LNG Site at the TOTE dock.

Dear Mr. Stobart:

GexCon was requested by Chicago Bridge & Iron (CB&I) to evaluate an LNG spill for the Puget Sound Energy (PSE) Tacoma site using the latest layout for the Totem Ocean Trailer Express (TOTE) dock under two conditions: high tide and low tide. The gas dispersion simulations used the geometry models shown in Figure ***1*** and Figure 2. In addition to determining if the flammable vapor cloud extends beyond the property line that can be built upon, this analysis determined if the cloud would encroach on the ship trailer loading ramp to the north. This is a path to egress in case of emergency and should remain passable in the event of a spill. The modeling considered the same ambient conditions and trench and sump properties described in the report GexCon-15-P515018-R-1_rev00. The spill parameters are summarized in Table 1. The complete list of simulations performed is given in Table 2.

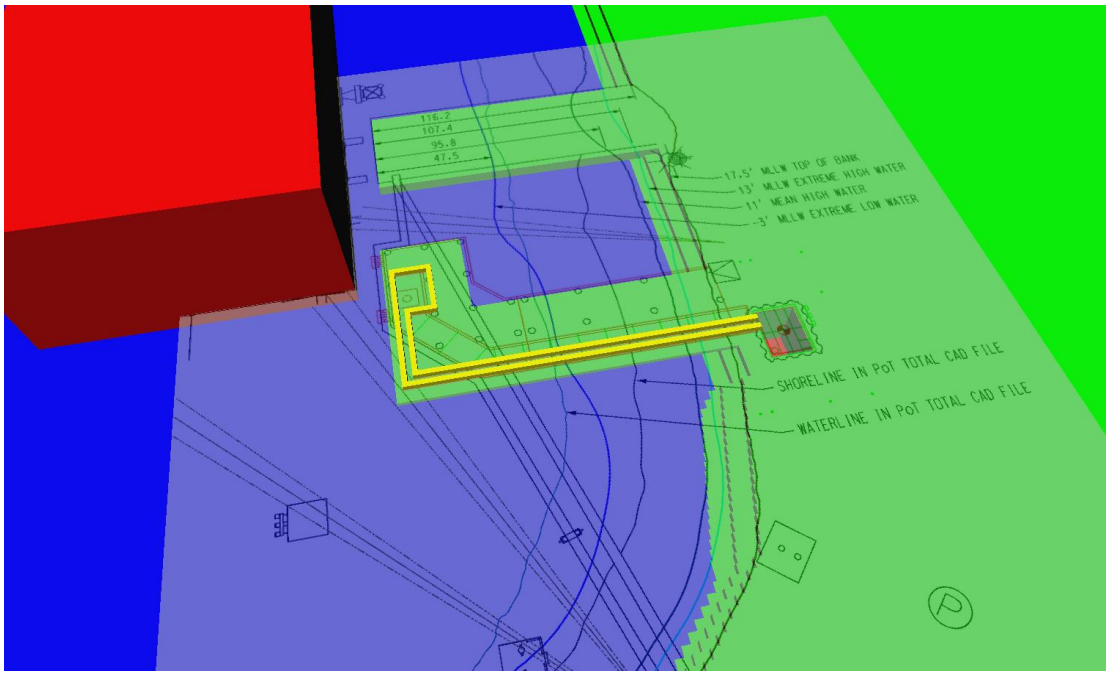

Figure 1. Tacoma site FLACS geometry, high tide.

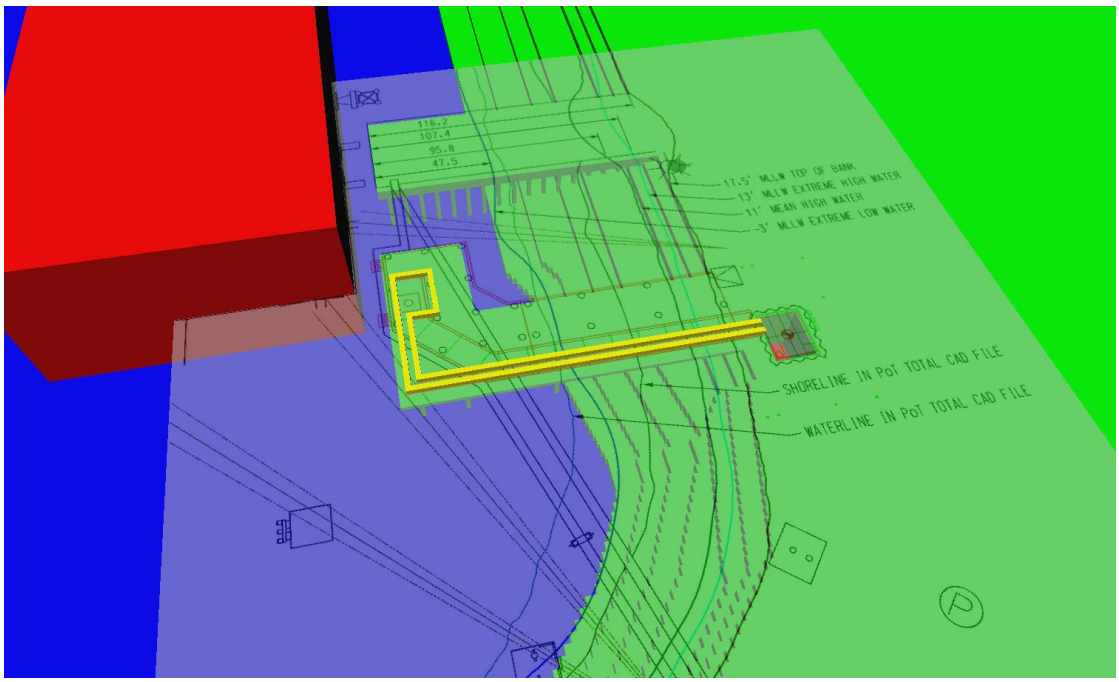

Figure 2. Tacoma site FLACS geometry, low tide.

Table 1. Scenario parameters for Tacoma.

Location	Spill Flow Rate [kg/s]	Duration [s]
TOTE dock	75.4	600

Table 2. FLACS vapor dispersion simulations for the LNG spill at the TOTE dock.

Run #	Spill location	Wind Speed [m/s]	Wind Direction [from]
115911	TOTE dock: high tide	1	NE
115912	TOTE dock: high tide	1	E
115913	TOTE dock: high tide	1	SE
115914	TOTE dock: high tide	1	S
115915	TOTE dock: high tide	1	SW
115916	TOTE dock: high tide	1	W
115917	TOTE dock: high tide	1	NW
115918	TOTE dock: high tide	1	N
115921	TOTE dock: high tide	2	NE
115922	TOTE dock: high tide	2	E

Run #	Spill location	Wind Speed [m/s]	Wind Direction [from]
115923	TOTE dock: high tide	2	SE
115924	TOTE dock: high tide	2	S
115925	TOTE dock: high tide	2	SW
115926	TOTE dock: high tide	2	W
115927	TOTE dock: high tide	2	NW
115928	TOTE dock: high tide	2	N
116911	TOTE dock: low tide	1	NE
116912	TOTE dock: low tide	1	E
116913	TOTE dock: low tide	1	SE
116914	TOTE dock: low tide	1	S
116915	TOTE dock: low tide	1	SW
116916	TOTE dock: low tide	1	W
116917	TOTE dock: low tide	1	NW
116918	TOTE dock: low tide	1	N
116921	TOTE dock: low tide	2	NE
116922	TOTE dock: low tide	2	E
116923	TOTE dock: low tide	2	SE
116924	TOTE dock: low tide	2	S
116925	TOTE dock: low tide	2	SW
116926	TOTE dock: low tide	2	W
116927	TOTE dock: low tide	2	NW
116928	TOTE dock: low tide	2	N

Figure 3 shows the layout of the 10-ft tall vapor barrier included in proximity of the TOTE sump and along the northern perimeter of the TOTE dock, in order to control the dispersion of the flammable LNG vapor clouds. The red line identifies an impermeable barrier while the green line represents a 10% porous barrier.

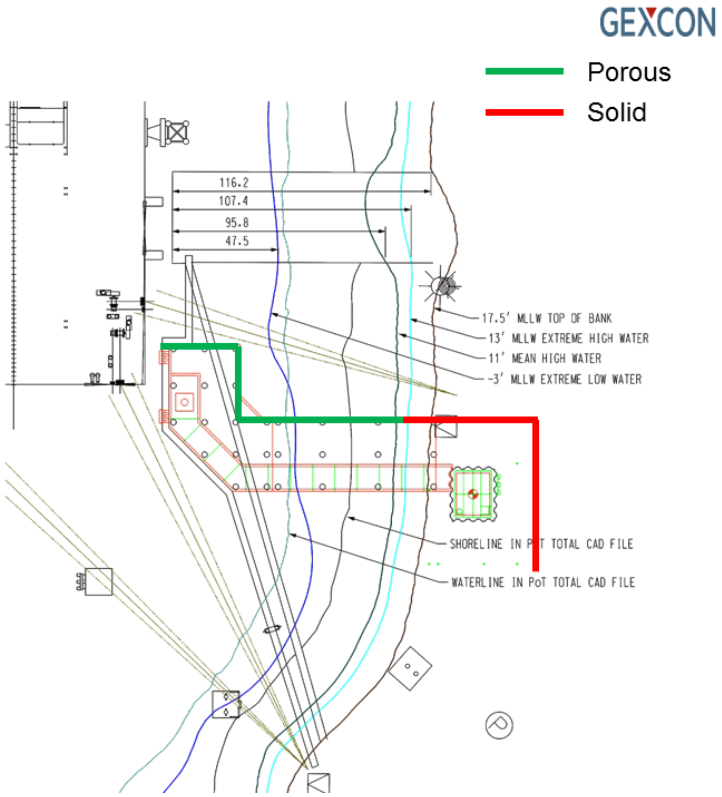

Figure 3. Vapor barrier layout.

The physical gas concentration limit below which ignition may not occur is known as the Lower Flammability Limit (LFL). However, flammable gas dispersion hazard analyses typically include a safety factor of 2, to account for modeling assumptions and other uncertainties.

In all simulations, the base grid spacing in the horizontal direction was set to 5 m. Horizontal and vertical grid refinement to a minimum of approximately 0.4 m was applied within the trenches; grid stretching was performed outside the region of interest for vapor cloud dispersion. All grid stretching and transitions were performed in compliance with FLACS modelling guidelines and consistent with the FLACS validation work.

Simulation Results

Figure 4 through Figure 7 show the 2D footprint of the LNG vapor clouds (at or above the ½-LFL concentration) for the simulations listed in Table 2; the footprint represents the cumulative overlay of the cloud position at each output time (10 seconds); the release location is identified by a red star.

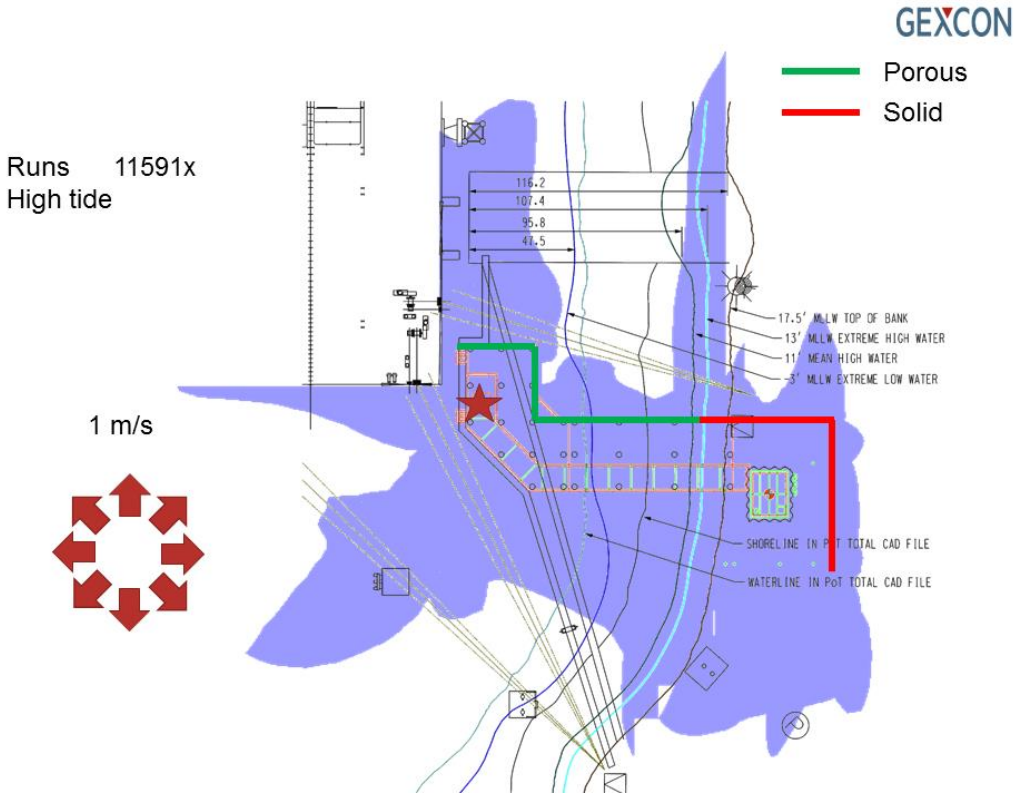

Figure 4. Footprint of the vapor clouds for an LNG spill into the TOTE dock trenches, high tide, with wind at 1 m/s from several directions.

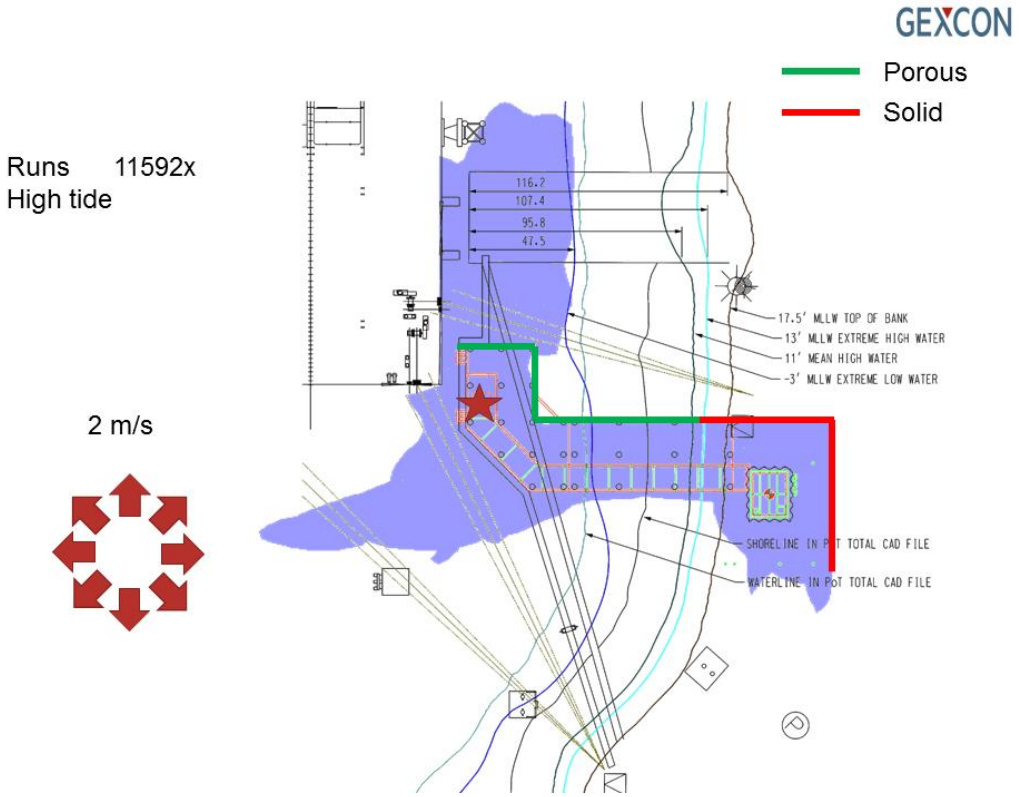

Figure 5. Footprint of the vapor clouds for an LNG spill into the TOTE dock trenches, high tide, with wind at 2 m/s from several directions.

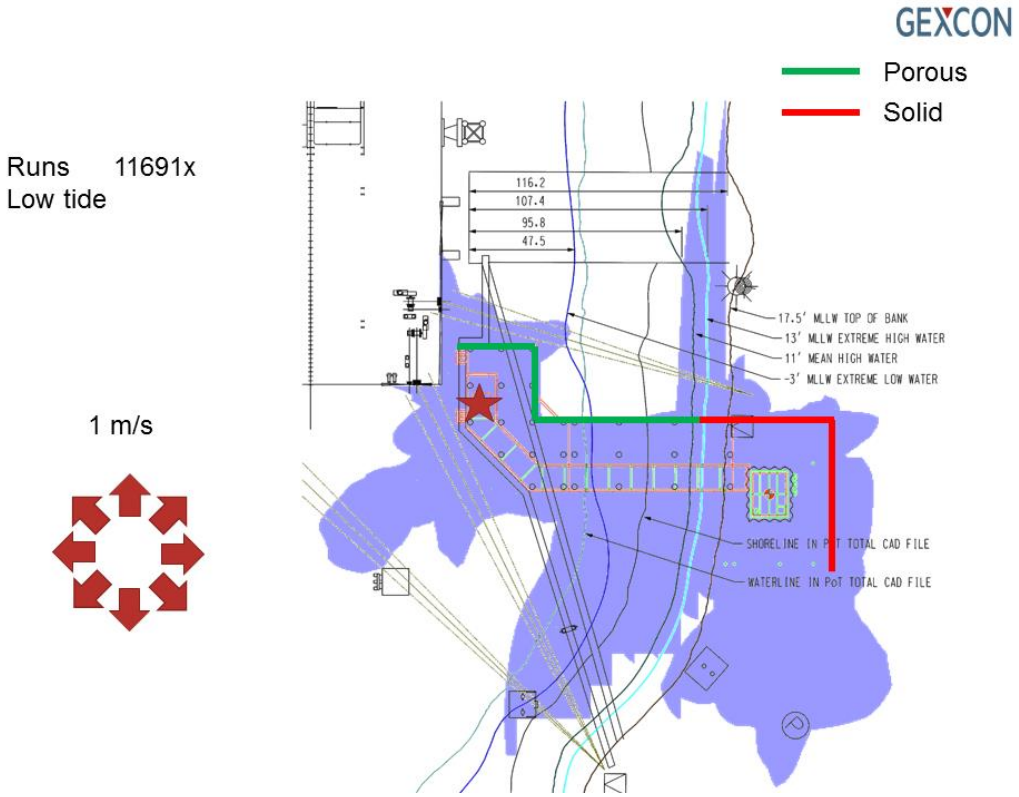

Figure 6. Footprint of the vapor clouds for an LNG spill into the TOTE dock trenches, low tide, with wind at 1 m/s from several directions.

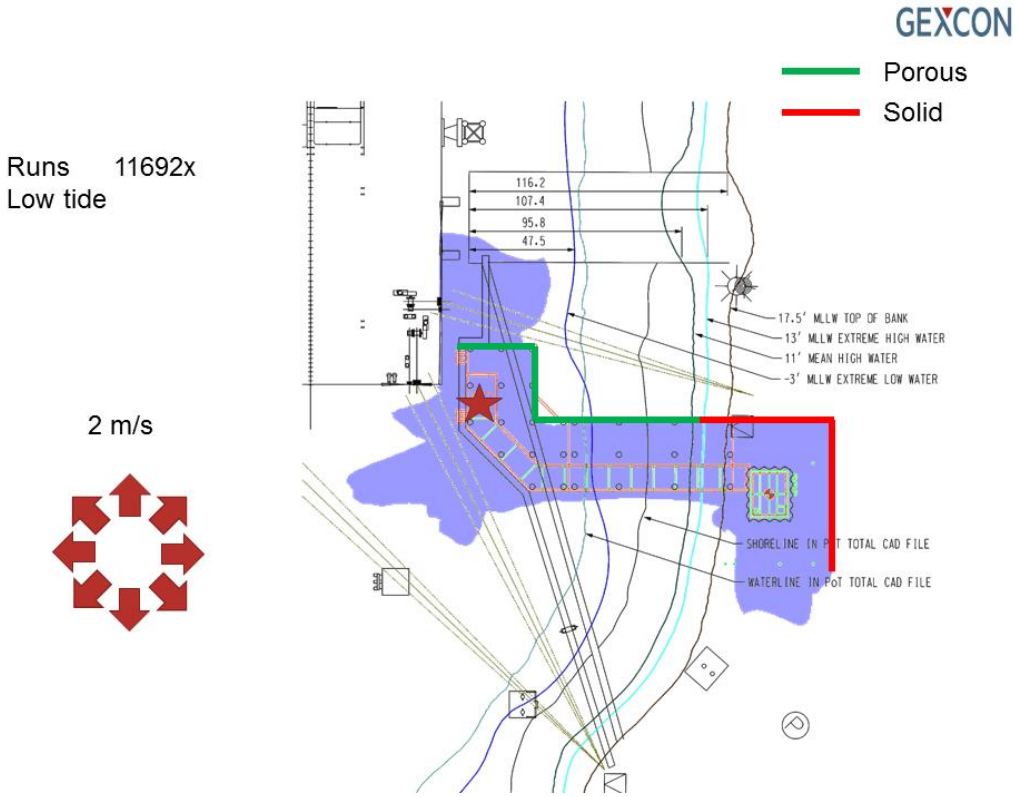

Figure 7. Footprint of the vapor clouds for an LNG spill into the TOTE dock trenches, low tide, with wind at 2 m/s from several directions.

Figure 4 through Figure 7 show the maximum 2D footprint of the LNG vapor clouds between sea level to the ceiling of the computational domain; these figures do not show whether the ½-LFL clouds reach the top of the trailer loading ramp (situated north of the TOTE dock) or if they spread beneath the trailer loading ramp. Therefore, 3D images of the LNG vapor clouds are shown in Figure 8 through Figure 12. Each figure caption specifies the geometry, the wind speed and the wind direction used in the simulation represented. The 3D figures show that the ½-LFL clouds spread below the trailer loading ramp without reaching above its surface.

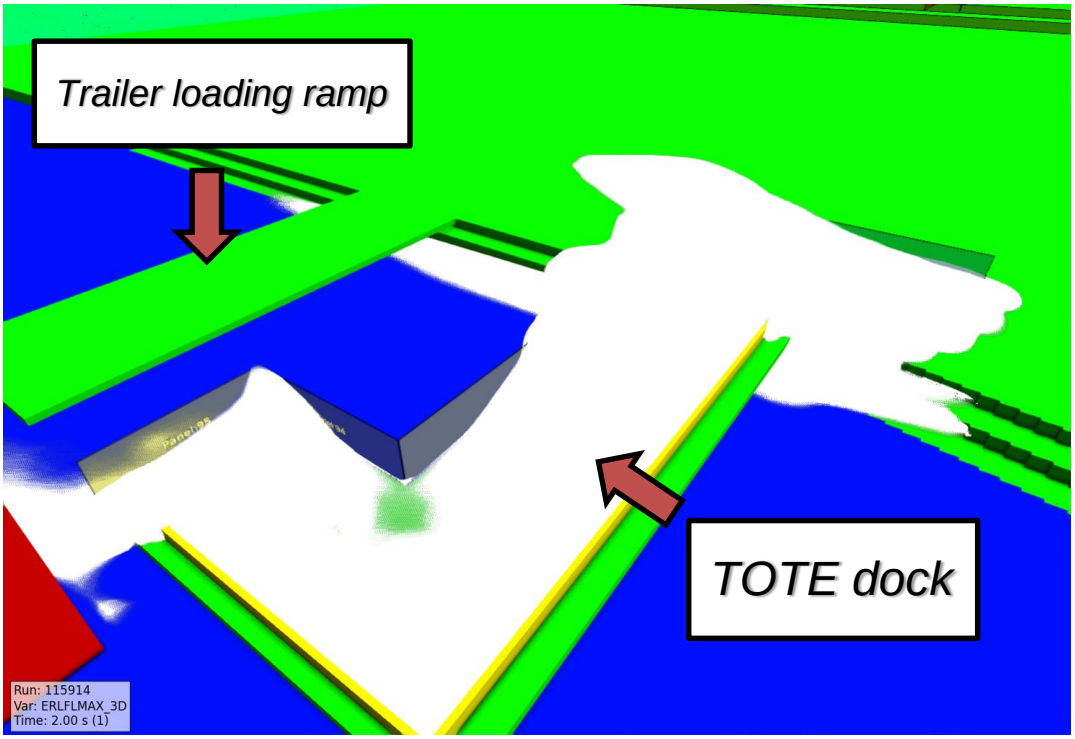

Figure 8. 3D vapor clouds for an LNG spill into the TOTE dock trenches, high tide, with wind at 1 m/s from the south.

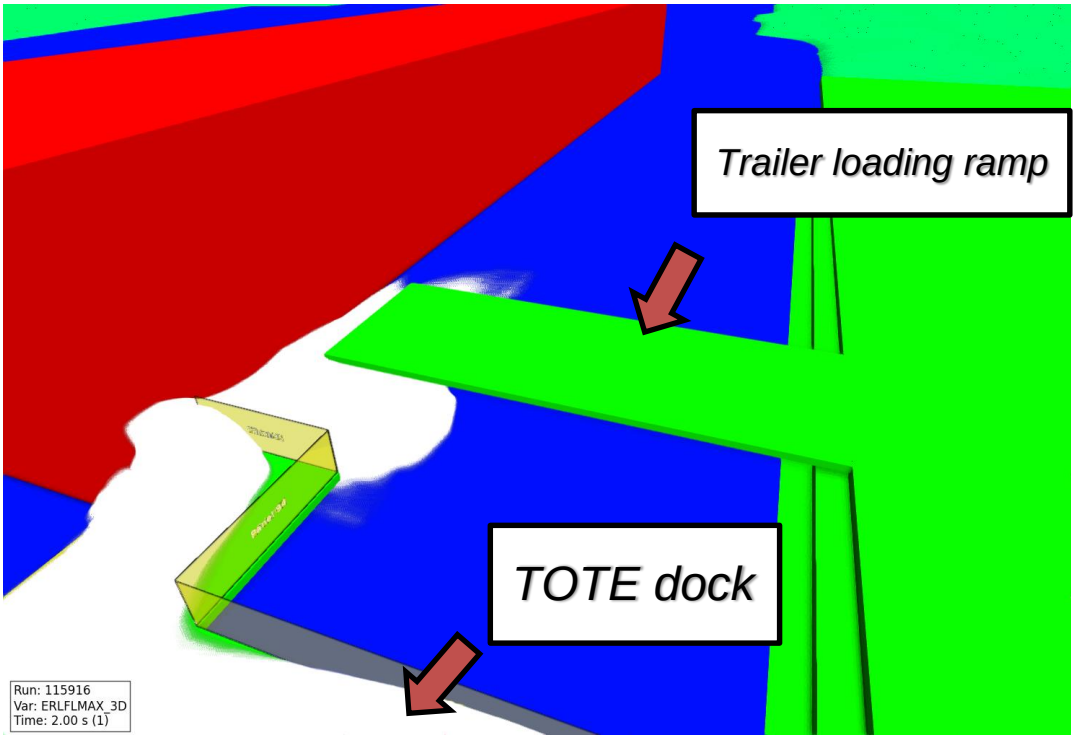

Figure 9. 3D vapor clouds for an LNG spill into the TOTE dock trenches, high tide, with wind at 1 m/s from the west.

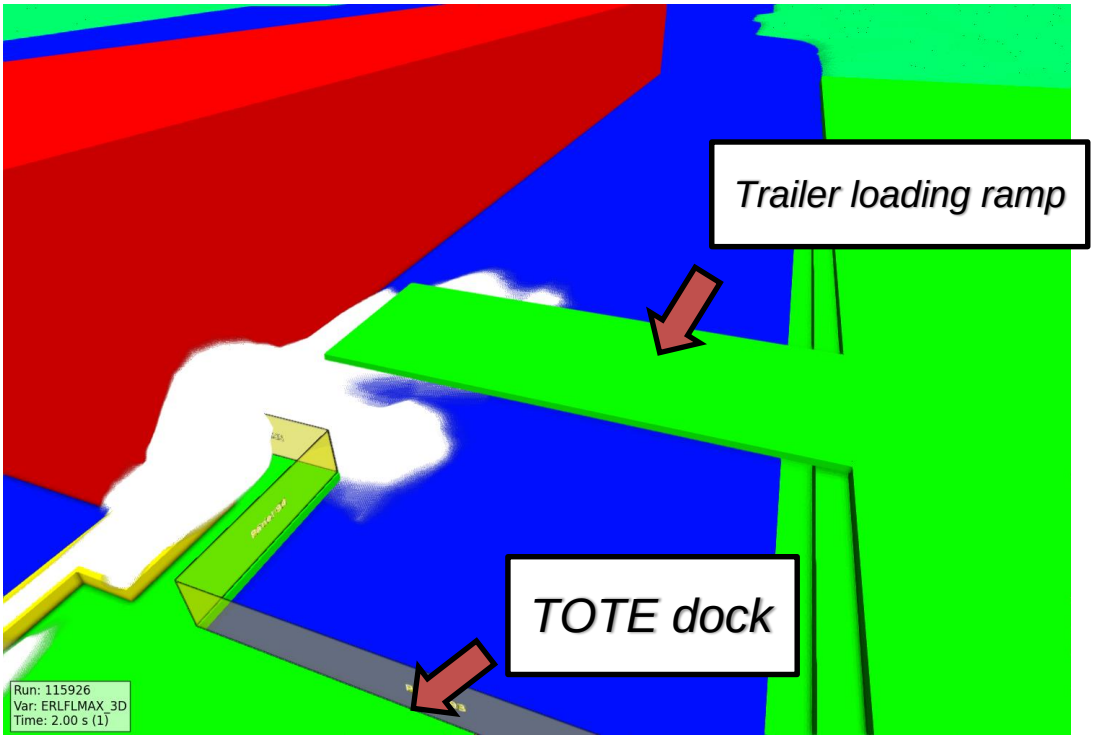

Figure 10. 3D vapor clouds for an LNG spill into the TOTE dock trenches, high tide, with wind at 2 m/s from the west.

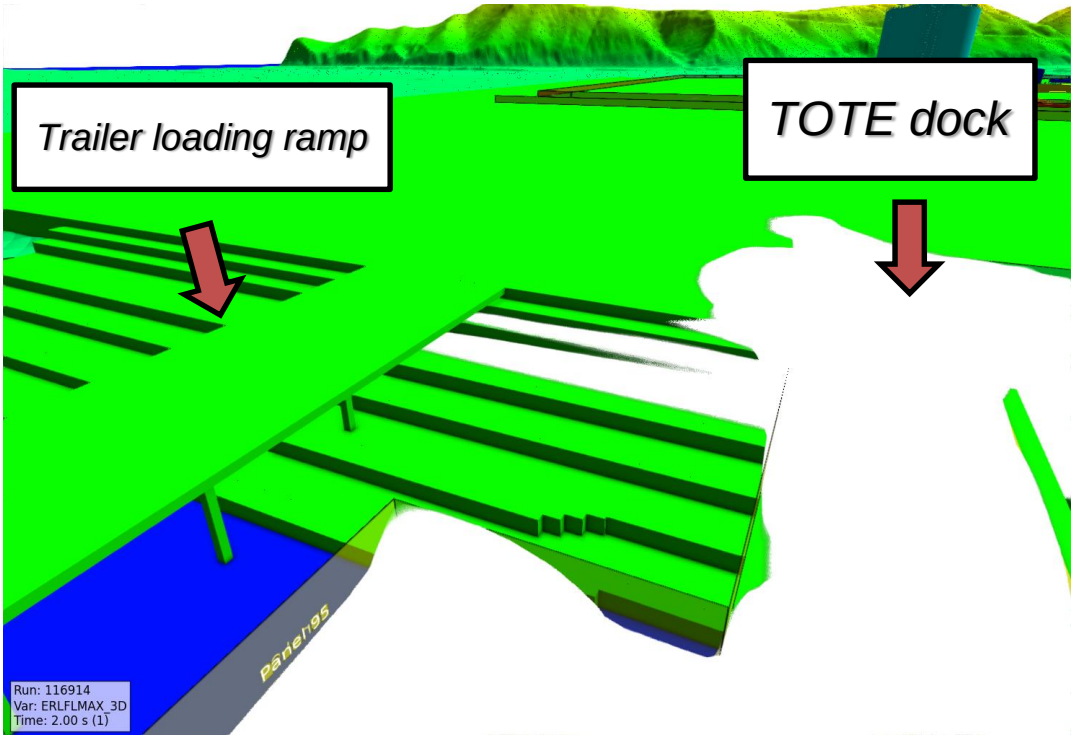

Figure 11. 3D vapor clouds for an LNG spill into the TOTE dock trenches, low tide, with wind at 1 m/s from the south.

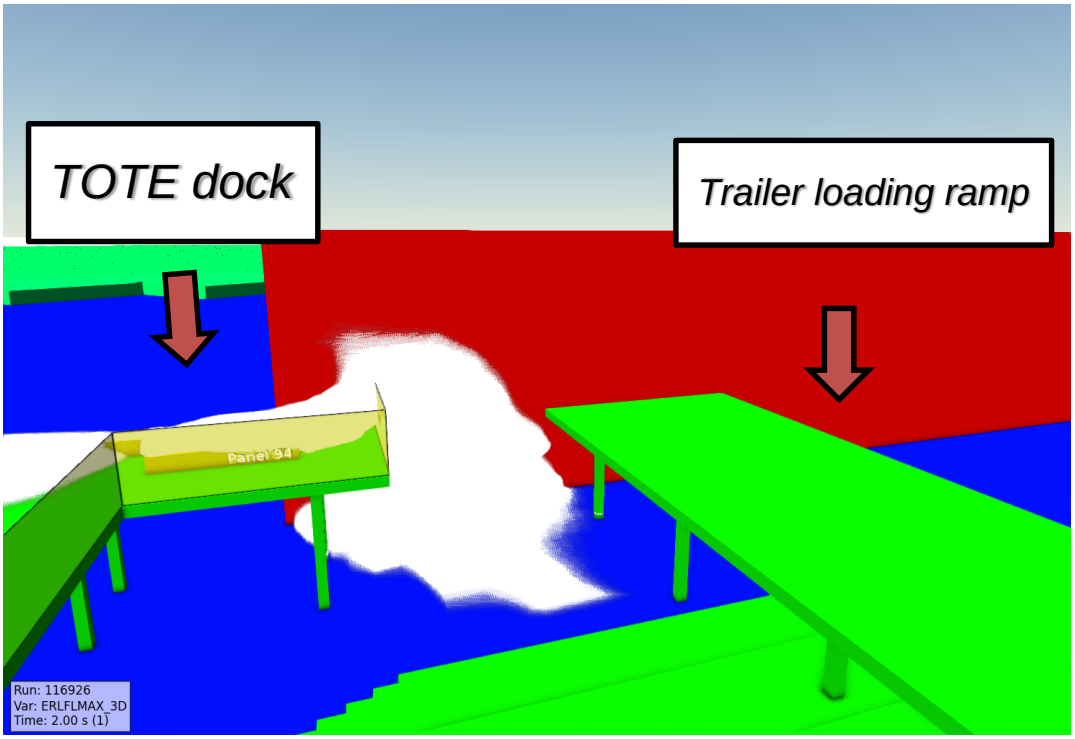

Figure 12. 3D vapor clouds for an LNG spill into the TOTE dock trenches, low tide, with wind at 2 m/s from the west.

Analysis of the Results

The flammable gas clouds from an LNG spill scenario at the TOTE dock were evaluated for the Tacoma site. As Figure 4 through Figure 12 indicate, the vapor clouds from LNG spill do not reach the top of the trailer loading ramp and remain within the property boundaries.

If you have any questions or comments, please do not hesitate to contact me at (301) 915-9925 or fgavelli@gexcon.com.

Best regards,

Filippo Gavelli, Ph.D., P.E.

Revision

Rev.	Date	Author	Checked by	Approved by	Reason for revision
00	9/17/2015	Filippo Gavelli, Ph.D., PE	Claudio Marsegan	Scott Davis, Ph.D., PE	Report issued to client

Disclaimer

The study presented in this report is intended for use by Chigaco Bridge & Iron (CB&I) and Puget Sound Energy (PSE). The scope of the study was strictly limited to performing computer modeling of the potential consequences from release scenarios specified by CB&I. The study used approved and/or accepted modeling tools and safety factors. This study did not address the likelihood of occurrence of any of the simulated scenarios.

GexCon has not visited the proposed site of the PSE Tacoma facility. GexCon has also not performed an independent evaluation of the processes and of the possible releases that may occur at the PSE Tacoma facility.

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PROJECT REPORT

Tacoma LNG – Dispersion Modeling

Chicago Bridge & Iron

Client	Author(s)
Mike Montgomery	Filippo Gavelli

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Document Info

Author(s)

Filippo Gavelli

Title

Tacoma LNG – Dispersion Modeling

Executive Summary

GexCon US, Inc. (GexCon) was contacted by Chicago Bridge & Iron (CB&I) to perform a hazard analysis for the Tacoma LNG facility to be located on the port of Tacoma, Washington.

This report presents the results of the following hazard analyses:

- Flammable vapor dispersion exclusion zones for design LNG spills into the liquefaction facility trenches and sumps;
- Flammable vapor dispersion exclusion zones for a single NG vapor release within the facility.

The vapor dispersion simulations were performed using GexCon's CFD modeling software FLACS, version 9.1. FLACS was approved by the U.S. DOT as an alternate model for vapor dispersion under 49 CFR 193.2059 on October 7, 2011.

The results of the hazard analysis presented in this report are as follows:

- The footprint of the vapor dispersion cloud (to ½-LFL) for the design LNG spills remains within the property boundaries;
- The footprint of the vapor dispersion cloud (to ½-LFL) for a single NG vapor release does not extend across a property line that may be built upon.

Project Info

Client
Chicago Bridge & Iron

Clients ref.
Mike Montgomery

GexCon Project No.
P515018

GexCon Project Name
Tacoma LNG – Dispersion Modeling

Revision

Rev.	Date	Author	Checked by	Approved by	Reason for revision
00	7/16/15	Filippo Gavelli, Ph.D., PE	Claudio Marsegan	Scott Davis, Ph.D., PE	Report issued to client

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Disclaimer

The study presented in this report is intended for use by Chicago Bridge & Iron and Puget Sound Energy (PSE) for regulatory purposes. The scope of the study was strictly limited to performing computer modeling of the potential consequences from accidental scenarios specified by Chicago Bridge & Iron. The study used approved and/or accepted modeling tools and applied safety factors to the results as specified by the regulatory bodies. In compliance with regulations, this study did not address the likelihood of occurrence of any of the simulated scenarios.

GexCon has not visited the proposed site of the Tacoma LNG facility. GexCon has also not performed an independent evaluation of the processes and of the possible accidental releases that may occur at the Tacoma LNG facility.

Chicago Bridge & Iron agrees that in no event shall GexCon, its officers, employees, or agents be liable for any direct, indirect, incidental, special, punitive or consequential damages arising out of or relating in any way to any opinions, conclusions and/or recommendations contained in this report. Chicago Bridge & Iron assumes full and complete responsibility for all uses and applications of this report, and agrees to indemnify and hold harmless GexCon against and from any and all liability, damages, losses, claims, demands, actions, causes of action, and costs including attorneys' fees and expenses arising out of any such use or application.

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1 Background

GexCon US, Inc. (GexCon) was contacted by Chicago Bridge & Iron (CB&I) to perform a hazard analysis for the Tacoma LNG facility to be located on the port of Tacoma, Washington.

This report presents the results of the following hazard analyses:

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2 Tacoma LNG facility

Puget Sound Energy (PSE) is planning to build and operate an LNG liquefaction plant (Tacoma LNG) in Tacoma, Washington, as shown in Figure 1. The Tacoma LNG facility includes a single LNG liquefaction unit, one LNG storage tank and associated facilities and equipment.

The FLACS geometry model of the area is shown in Figure 2.

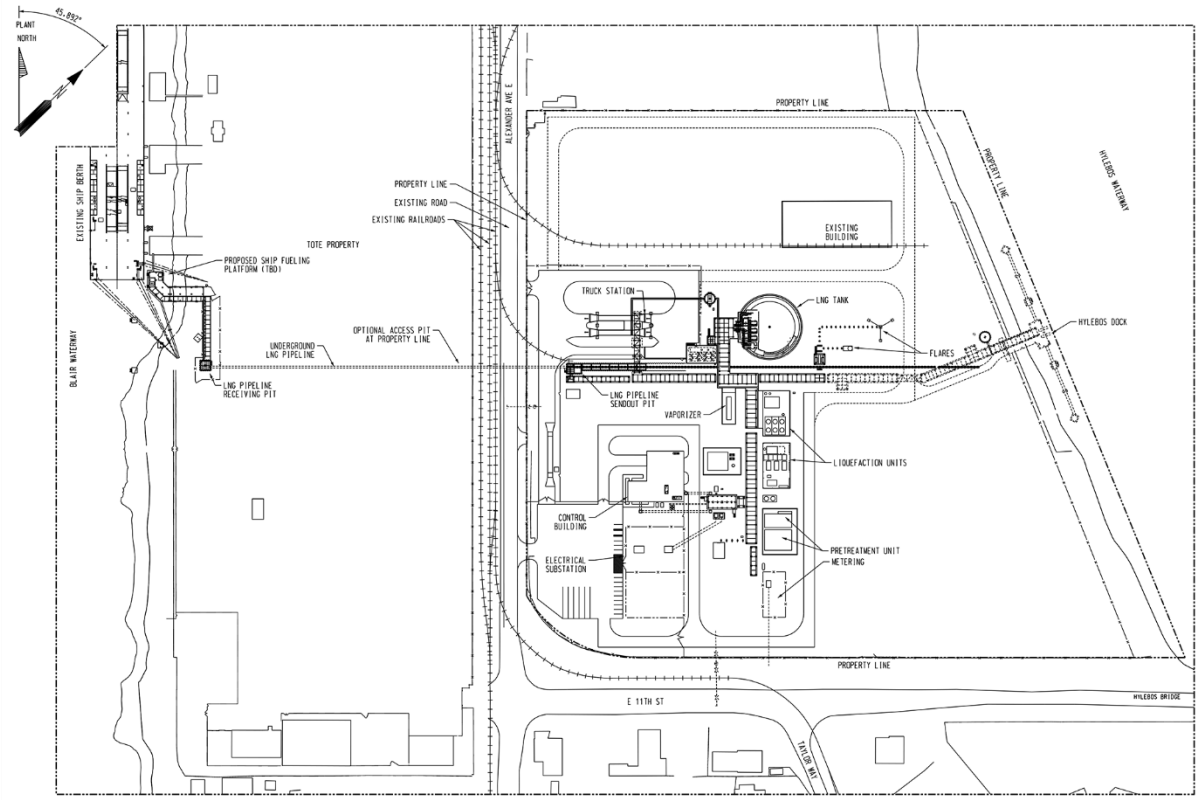

Figure 1. Plan view of the Tacoma LNG facility.

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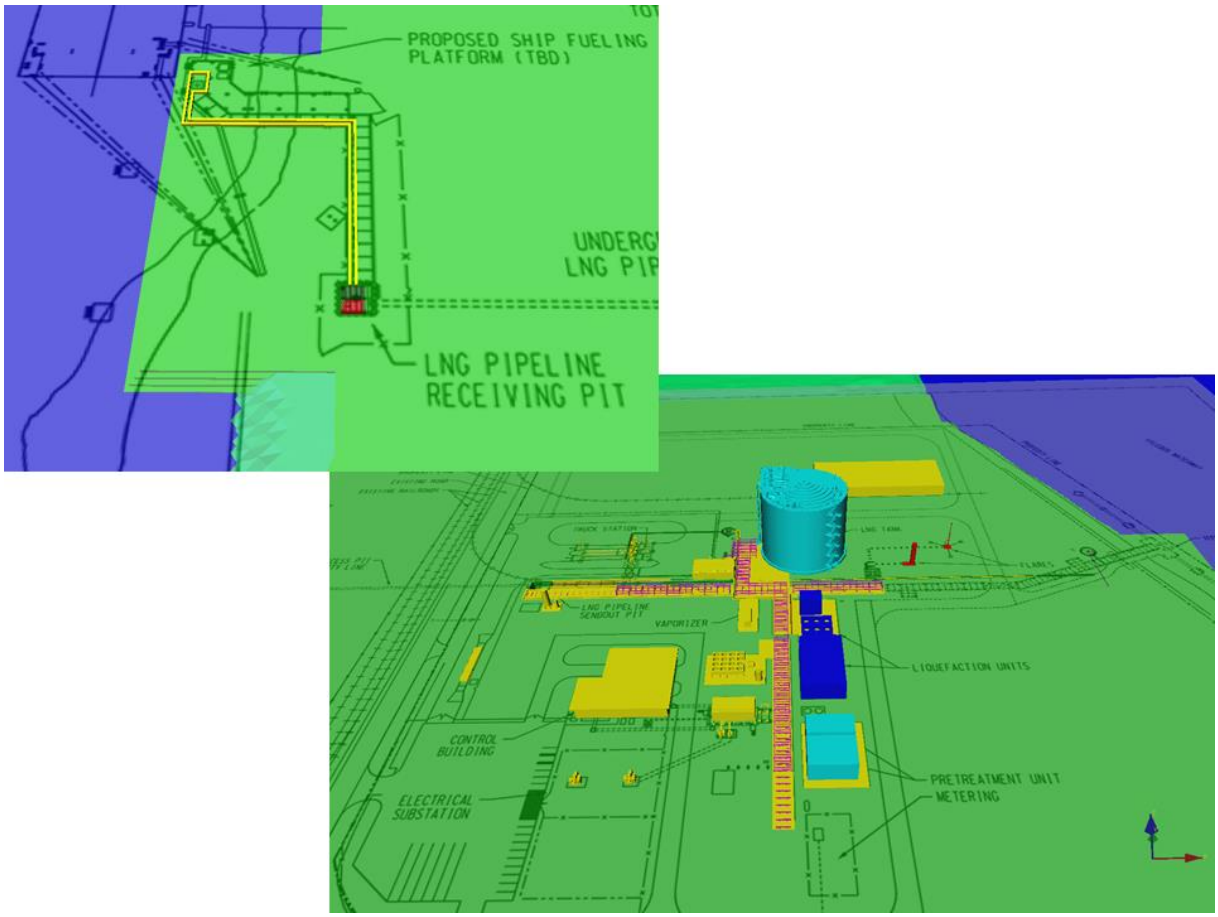

Figure 2. FLACS model of the facility.

The project will include an LNG spill conveyance system, consisting of trenches running alongside all piping, designed to collect liquid spills and direct them to different sumps. The trench and sump layout is shown in Figure 3. The sumps are highlighted in orange while the trenches are highlighted in different colors based on their minimum depth; all trenches are 2 ft wide. Yellow arrows show the direction in which the liquid flows.

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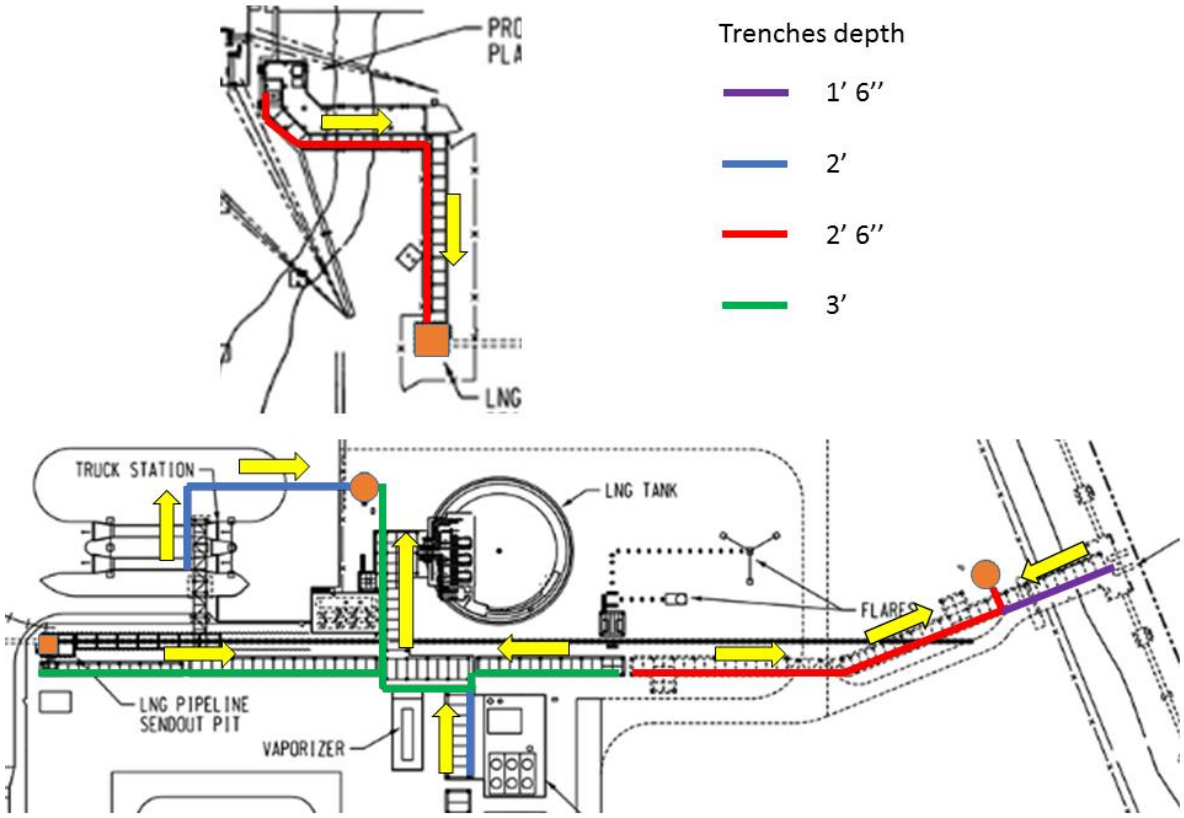

Figure 3. Trenches (in purple, blue, red and green) and sumps (in orange) layout.

The two Totem Ocean Trailer Express (TOTE) sumps (located on the western end of the underground pipeline leading to the ship fueling platform and near the western LNG pipeline sendout pit on the facility property) will measure 18.86 ft by 14.6 ft by 20 ft deep; the process sump (near the LNG tank) will measure 22.25 ft (diameter) by 21 ft deep; the HYLEBOS sump (located on the HYLEBOS dock) will measure 22.25 ft (diameter) by 15 ft deep.

All trenches and sumps will be constructed of regular concrete, whose properties are listed in Table 1.

Table 1. Thermophysical properties of concrete for LNG vapor dispersion calculations.

Material	Thermal Conductivity [W/(m·K)]	Thermal Diffusivity [m^2/s]
Regular Concrete	1.1	10^{-6}

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2.1 Ambient conditions

Ambient conditions for vapor dispersion hazard calculations are specified in federal regulations. The values used in this analysis are consistent with regulatory requirements in 49 CFR § 193.2059 and are summarized in Table 2.

Table 2. Ambient parameters.

Parameter	Value
Ambient Temperature	50.9°F (10.5°C)
Relative Humidity	50% [1]
Wind Speed	various[2]
Atmospheric Stability Class	F
Ground Roughness	0.03 m

2.2 Vapor Fences

Figure 2 shows the FLACS 3D geometry model of the Tacoma LNG facility. A vapor barrier was included in proximity of the piperack, in order to control the dispersion of the flammable NG vapor clouds (Figure 4).

Other vapor barriers were placed at strategic locations, as shown in Figure 5. All barriers are 8 ft tall and permeable (10% porosity), based on typical slatted chain link fencing.

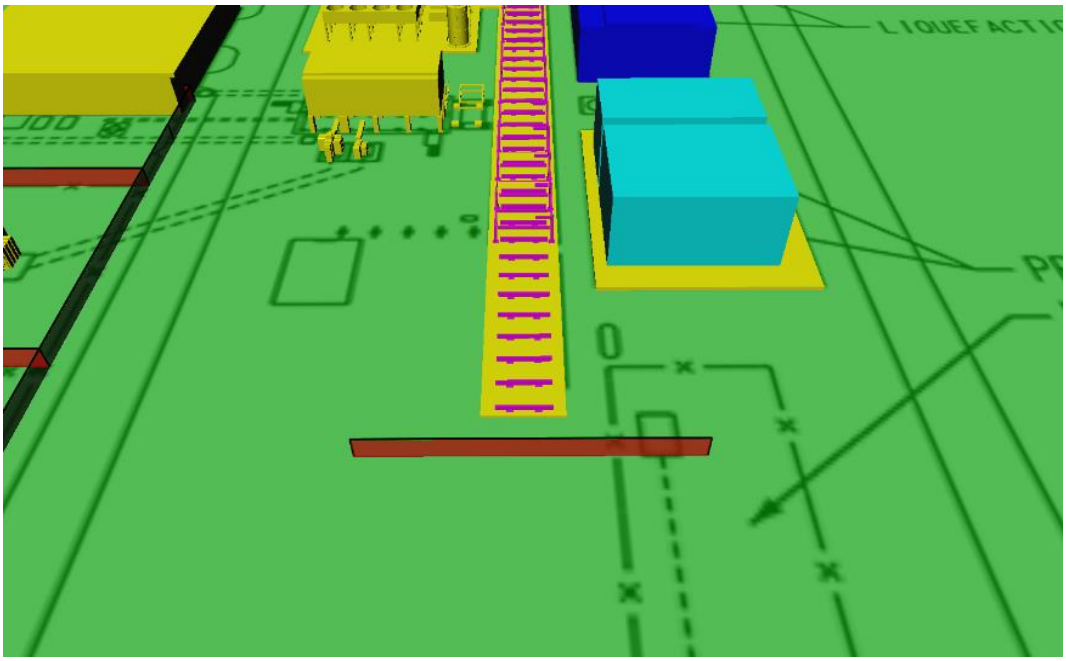

Figure 4. Vapor barrier for the NG vapor dispersion simulations.

[1] The effect of moisture condensation is not included in the FLACS vapor dispersion simulations.
[2] The analysis includes sensitivity to wind speed.

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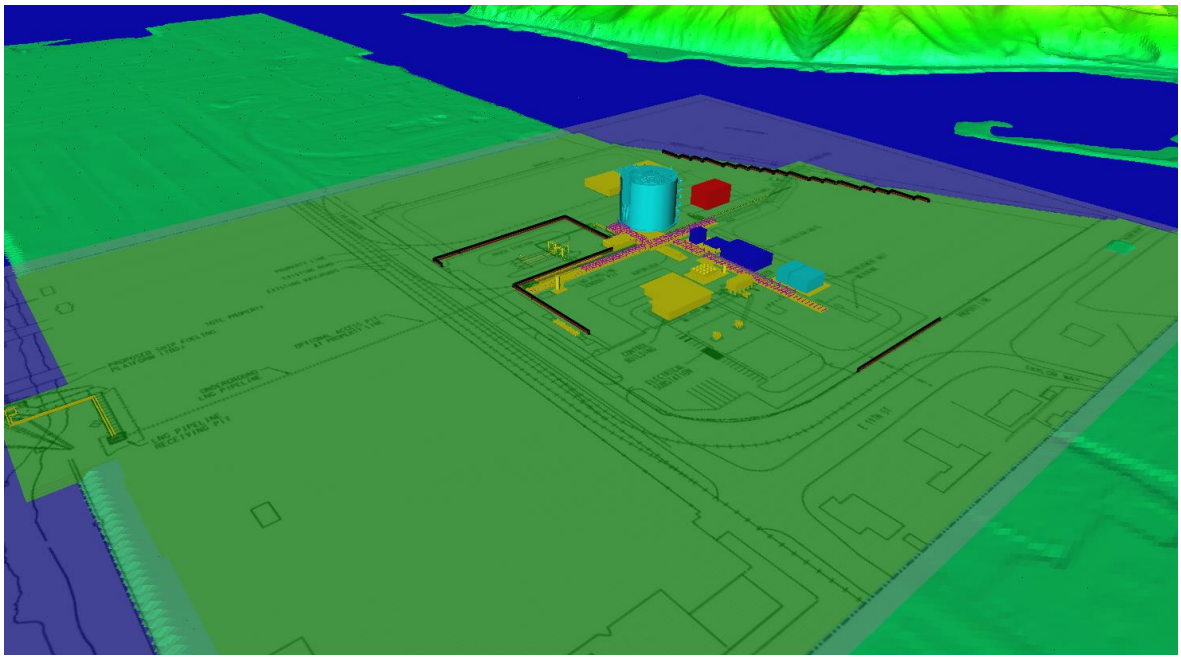

Figure 5. Vapor barriers for the Tacoma LNG facility.

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3 Vapor Dispersion Hazard Analysis

3.1 LNG Spills

Federal regulations (49 CFR § 193.2059) require that the flammable vapor dispersion distances (to 50% of the lower flammable limit, ½-LFL) be calculated for a design spill into an LNG impoundment. In this analysis, GexCon used the CFD model FLACS to calculate the LNG pool spread, vaporization and vapor cloud dispersion from liquefied gas spills into trenches and the TOTE sump (facility side). The LNG spill parameters were provided by CB&I and are summarized in Table 3. All simulations assumed a constant release rate for a duration of 10 minutes. Figure 6 shows the location of each spill, indicated by a red star and the correspondent scenario number. The complete list of simulations performed is given in Table 4.

Table 3. Release parameters for LNG spills into trenches and the TOTE sump (facility side).

Scenario #	Spill location	Spill Flow Rate [kg/s]
1	TOTE dock	75.4
2	TOTE pipeline sump (facility side)	83.9
3	Western piperack	83.9
4	Truck loading	7.7
5	Header pipe	83.9
6	Rundown line	6.3
7	HYLEBOS piperack (facility side)	89.6
8	HYLEBOS piperack (HYLEBOS dock side)	89.6
9	HYLEBOS dock	89.6

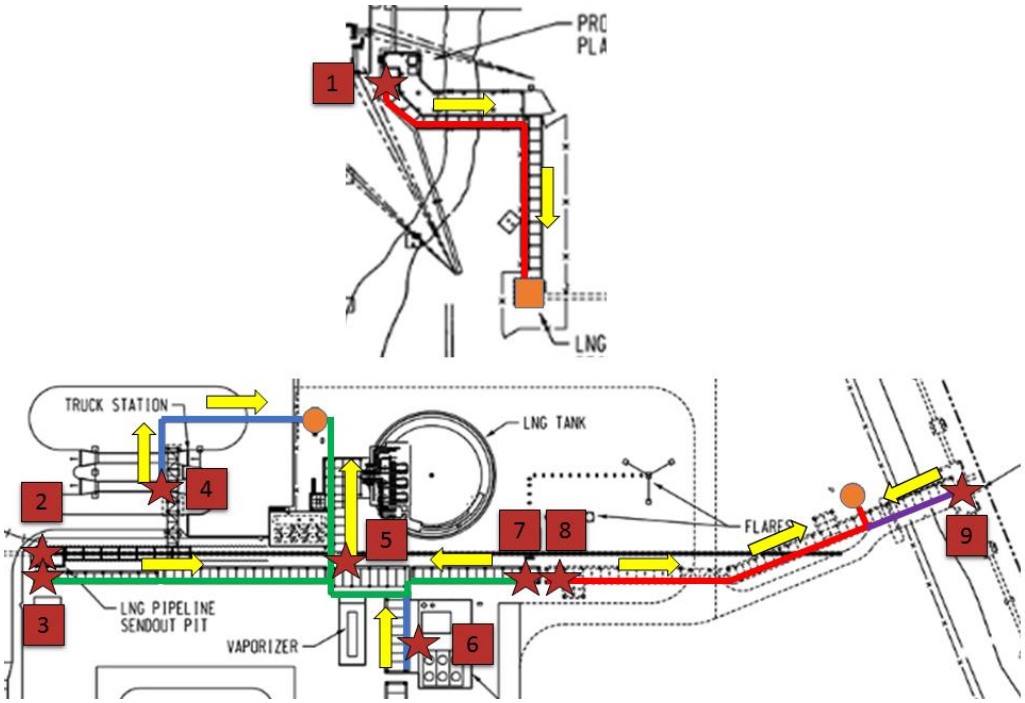

Figure 6. Location of each spill, indicated by a red star and the correspondent scenario number.

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Table 4. FLACS vapor dispersion simulations for LNG spills into trenches and the TOTE sump.

Scenario #	Run #	Spill location	Wind Speed [m/s]	Wind Direction [from]
1	**111911**	TOTE dock	1	NE
1	**111912**	TOTE dock	1	E
1	**111913**	TOTE dock	1	SE
1	**111914**	TOTE dock	1	S
1	**111918**	TOTE dock	1	N
1	**111921**	TOTE dock	2	NE
1	**111922**	TOTE dock	2	E
1	**111923**	TOTE dock	2	SE
1	**111924**	TOTE dock	2	S
1	**111928**	TOTE dock	2	N
2	**121911**	TOTE pipeline sump (facility side)	1	NE
2	**121912**	TOTE pipeline sump (facility side)	1	E
2	**121913**	TOTE pipeline sump (facility side)	1	SE
2	**121914**	TOTE pipeline sump (facility side)	1	S
2	**121918**	TOTE pipeline sump (facility side)	1	N
2	**121921**	TOTE pipeline sump (facility side)	2	NE
2	**121922**	TOTE pipeline sump (facility side)	2	E
2	**121923**	TOTE pipeline sump (facility side)	2	SE
2	**121924**	TOTE pipeline sump (facility side)	2	S
2	**121928**	TOTE pipeline sump (facility side)	2	N
3	**131911**	Western piperack	1	NE
3	**131912**	Western piperack	1	E
3	**131913**	Western piperack	1	SE
3	**131914**	Western piperack	1	S
3	**131918**	Western piperack	1	N
3	**131921**	Western piperack	2	NE
3	**131922**	Western piperack	2	E
3	**131923**	Western piperack	2	SE
3	**131924**	Western piperack	2	S
3	**131928**	Western piperack	2	N
4	**140911**	Truck loading	1	NE
4	**140912**	Truck loading	1	E
4	**140913**	Truck loading	1	SE
4	**140914**	Truck loading	1	S
4	**140915**	Truck loading	1	SW
4	**140916**	Truck loading	1	W
4	**140921**	Truck loading	2	NE
4	**140922**	Truck loading	2	E
4	**140923**	Truck loading	2	SE
4	**140924**	Truck loading	2	S
4	**140925**	Truck loading	2	SW
4	**140926**	Truck loading	2	W
5	**151912**	Header pipe	1	E
5	**151914**	Header pipe	1	S
5	**151916**	Header pipe	1	W
5	**151918**	Header pipe	1	N
5	**151922**	Header pipe	2	E
5	**151924**	Header pipe	2	S
5	**151926**	Header pipe	2	W
5	**151928**	Header pipe	2	N
6	**161912**	Rundown line	1	E
6	**161914**	Rundown line	1	S
6	**161916**	Rundown line	1	W

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Scenario #	Run #	Spill location	Wind Speed [m/s]	Wind Direction [from]
6	**161918**	Rundown line	1	N
6	**161922**	Rundown line	2	E
6	**161924**	Rundown line	2	S
6	**161926**	Rundown line	2	W
6	**161928**	Rundown line	2	N
7	**171912**	HYLEBOS piperack (facility side)	1	E
7	**171914**	HYLEBOS piperack (facility side)	1	S
7	**171916**	HYLEBOS piperack (facility side)	1	W
7	**171918**	HYLEBOS piperack (facility side)	1	N
7	**171922**	HYLEBOS piperack (facility side)	2	E
7	**171924**	HYLEBOS piperack (facility side)	2	S
7	**171926**	HYLEBOS piperack (facility side)	2	W
7	**171928**	HYLEBOS piperack (facility side)	2	N
8	**181914**	HYLEBOS piperack (HYLEBOS dock side)	1	S
8	**181915**	HYLEBOS piperack (HYLEBOS dock side)	1	SW
8	**181916**	HYLEBOS piperack (HYLEBOS dock side)	1	W
8	**181917**	HYLEBOS piperack (HYLEBOS dock side)	1	NW
8	**181918**	HYLEBOS piperack (HYLEBOS dock side)	1	N
8	**181924**	HYLEBOS piperack (HYLEBOS dock side)	2	S
8	**181925**	HYLEBOS piperack (HYLEBOS dock side)	2	SW
8	**181926**	HYLEBOS piperack (HYLEBOS dock side)	2	W
8	**181927**	HYLEBOS piperack (HYLEBOS dock side)	2	NW
8	**181928**	HYLEBOS piperack (HYLEBOS dock side)	2	N
9	**190914**	HYLEBOS dock	1	S
9	**190915**	HYLEBOS dock	1	SW
9	**190916**	HYLEBOS dock	1	W
9	**190917**	HYLEBOS dock	1	NW
9	**190918**	HYLEBOS dock	1	N
9	**190924**	HYLEBOS dock	2	S
9	**190925**	HYLEBOS dock	2	SW
9	**190926**	HYLEBOS dock	2	W
9	**190927**	HYLEBOS dock	2	NW
9	**190928**	HYLEBOS dock	2	N

In all simulations, the base grid spacing in the horizontal direction was set to 5 m. Horizontal and vertical grid refinement to a minimum of approximately 0.3 m was applied within the trenches; grid stretching was performed outside the region of interest for vapor cloud dispersion. All grid stretching and transitions were performed in compliance with FLACS modelling guidelines and consistent with the FLACS validation work.

Simulation Results

Figure 7 through Figure 24 show the footprint of the LNG vapor clouds (at or above the ½-LFL concentration) for the simulations listed in Table 4; the footprint represents the cumulative overlay of the cloud position at each output time; the release location is identified by a red star.

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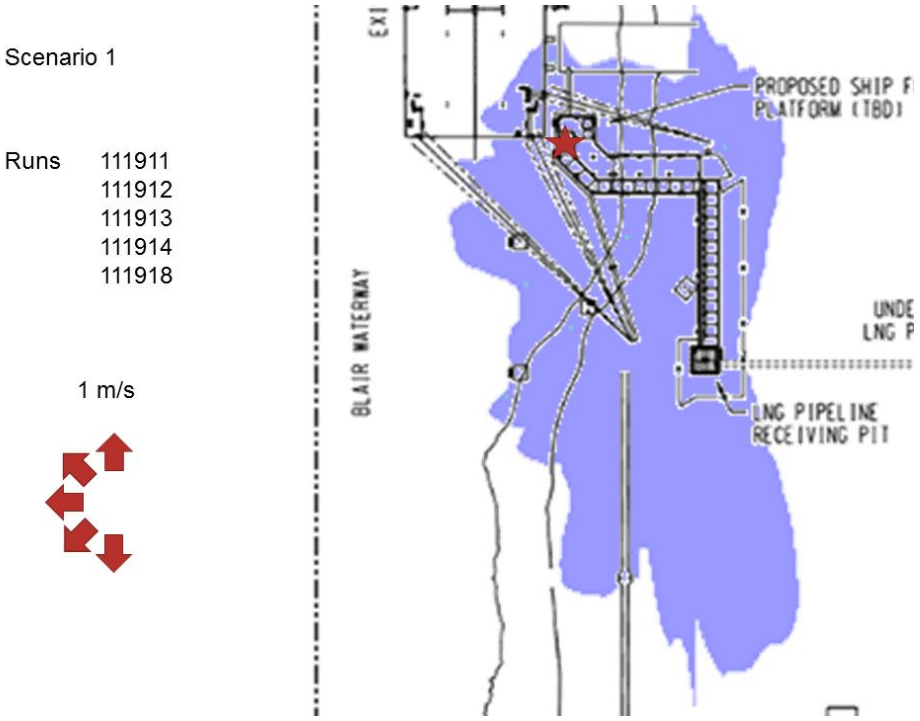

Figure 7. Footprint of the vapor clouds for an LNG spill into the TOTE dock trenches, with wind at 1 m/s from several directions.

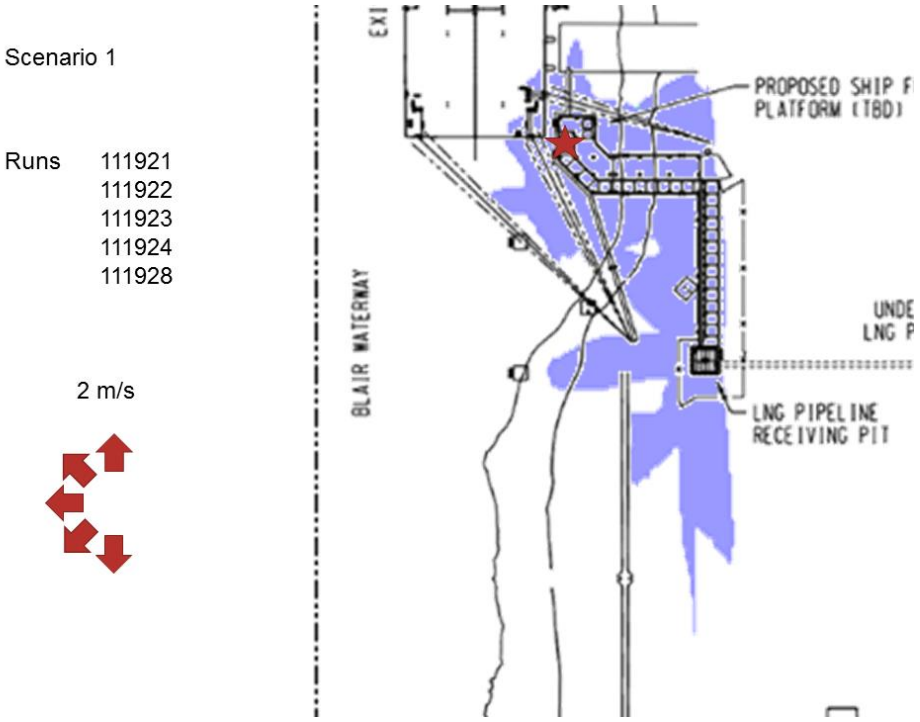

Figure 8. Footprint of the vapor clouds for an LNG spill into the TOTE dock trenches, with wind at 2 m/s from several directions.

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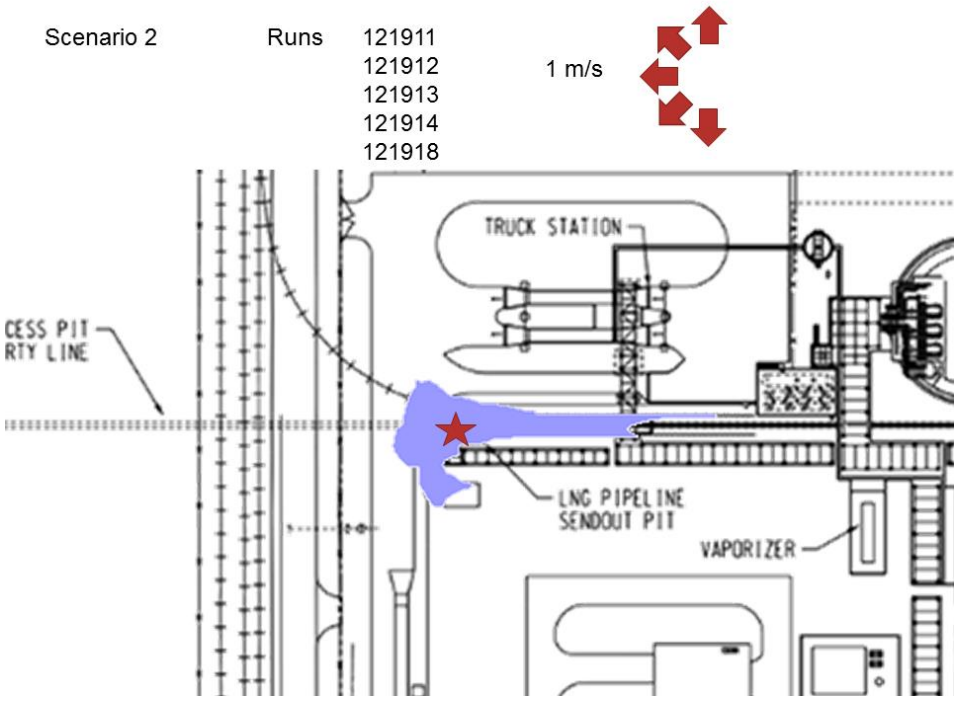

Figure 9. Footprint of the vapor clouds for an LNG spill into the TOTE sump (facility side), with wind at 1 m/s from several directions.

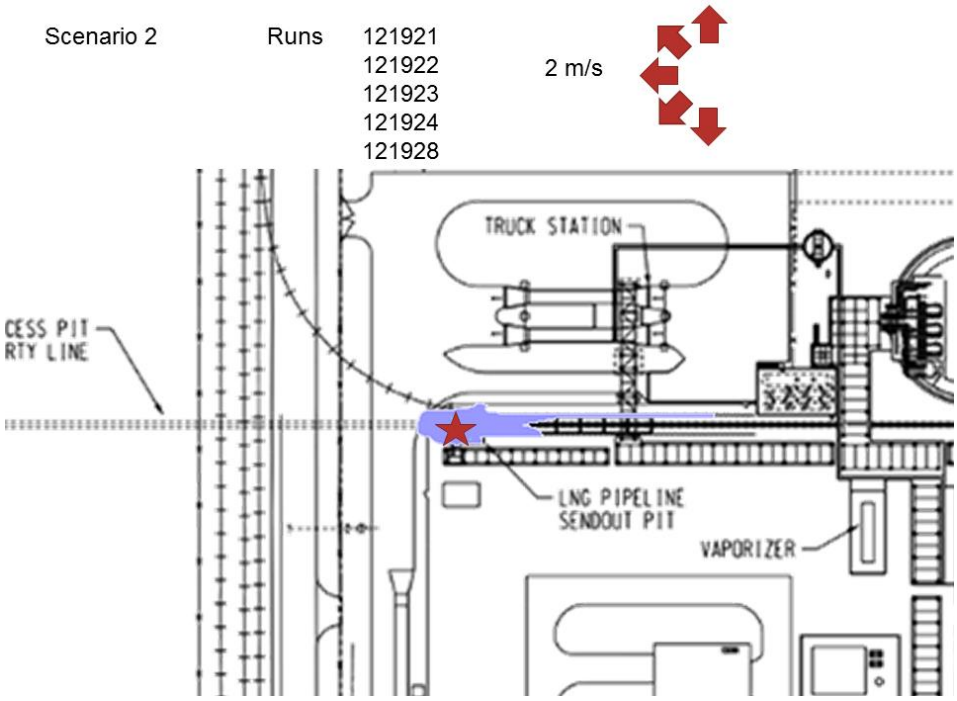

Figure 10. Footprint of the vapor clouds for an LNG spill into the TOTE sump (facility side), with wind at 2 m/s from several directions.

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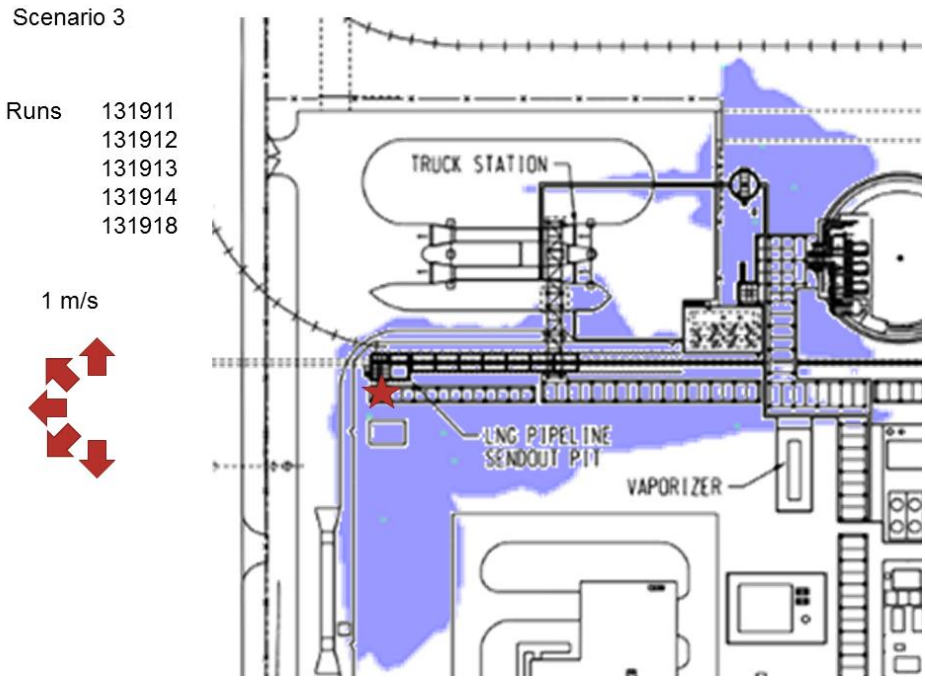

Figure 11. Footprint of the vapor clouds for an LNG spill into the western piperack trenches, with wind at 1 m/s from several directions.

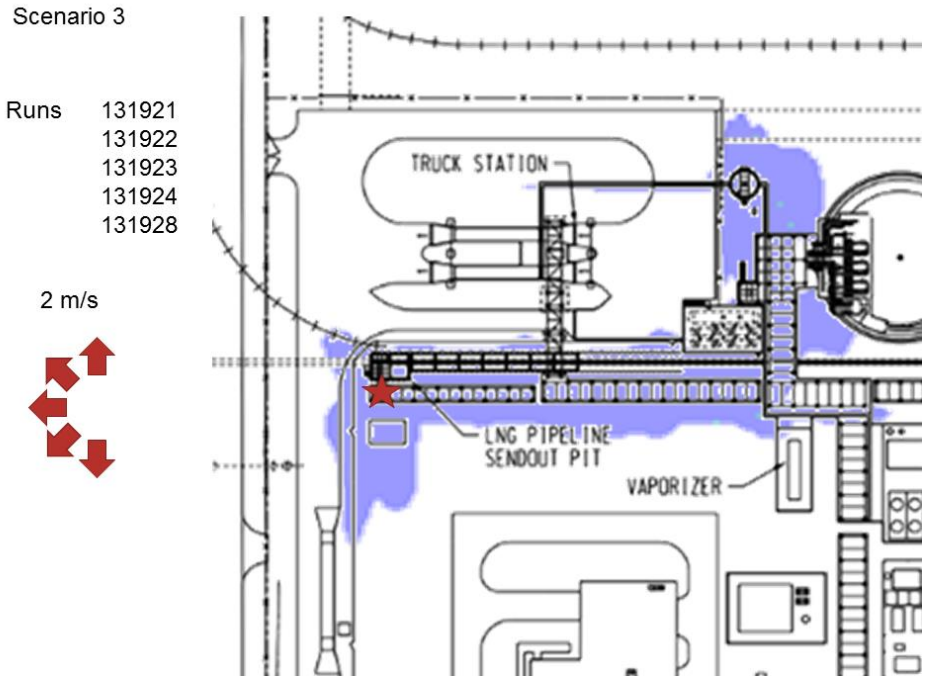

Figure 12. Footprint of the vapor clouds for an LNG spill into the western piperack trenches, with wind at 2 m/s from several directions.

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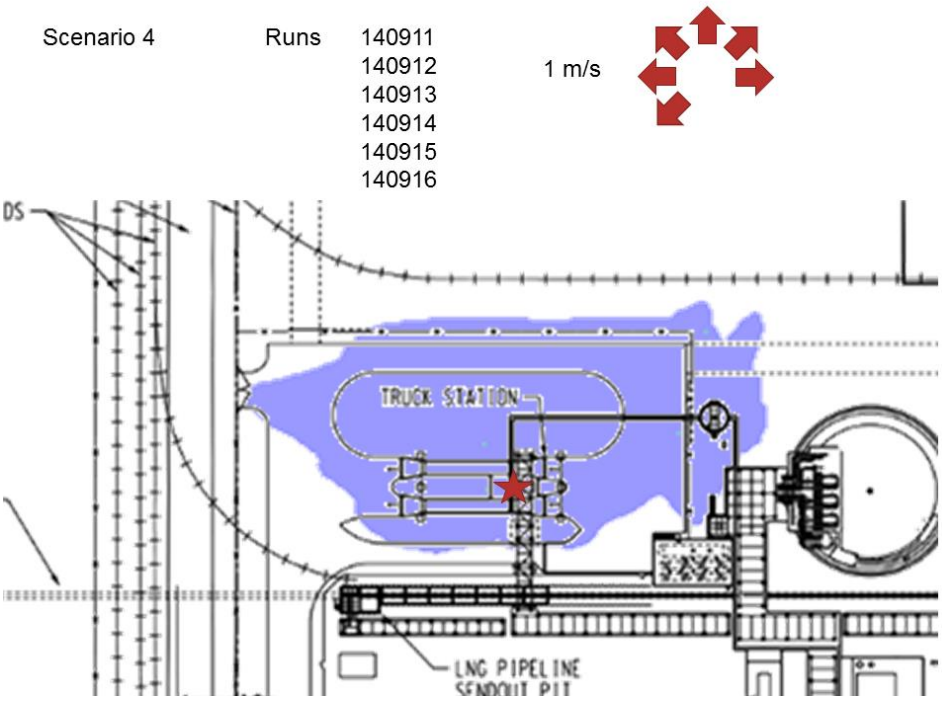

Figure 13. Footprint of the vapor clouds for an LNG spill into the truck loading trenches, with wind at 1 m/s from several directions.

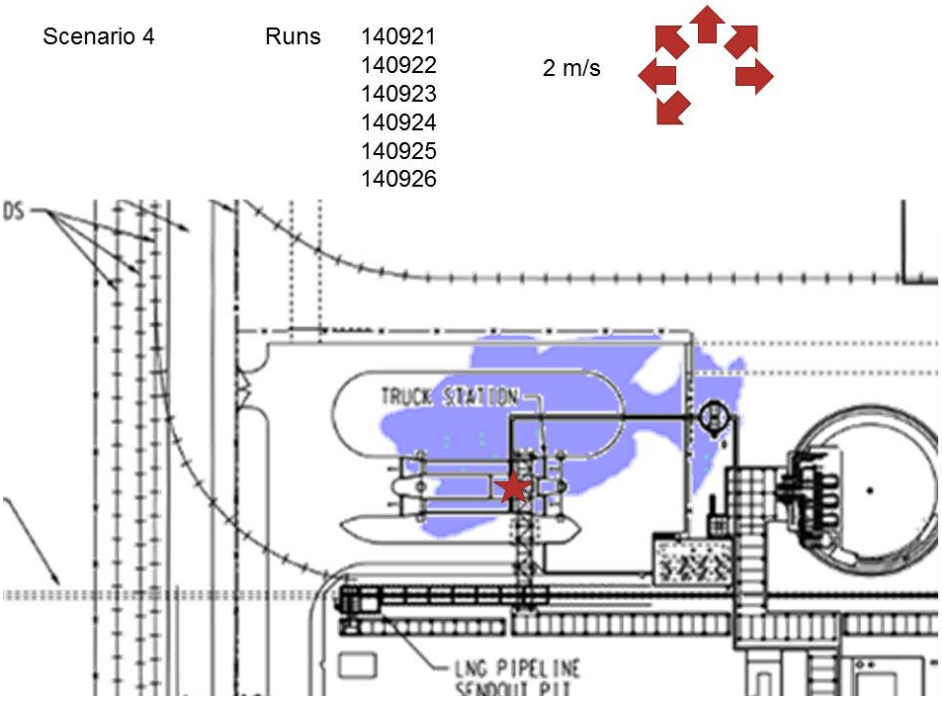

Figure 14. Footprint of the vapor clouds for an LNG spill into the truck loading trenches, with wind at 2 m/s from several directions.

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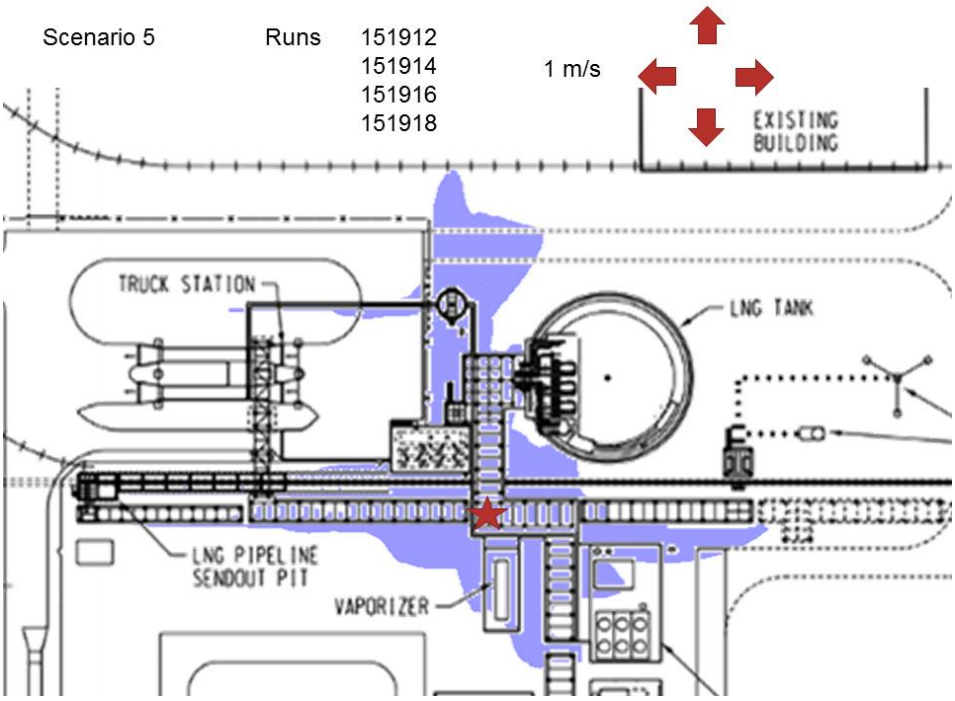

Figure 15. Footprint of the vapor clouds for an LNG spill into the header pipe trenches, with wind at 1 m/s from several directions.

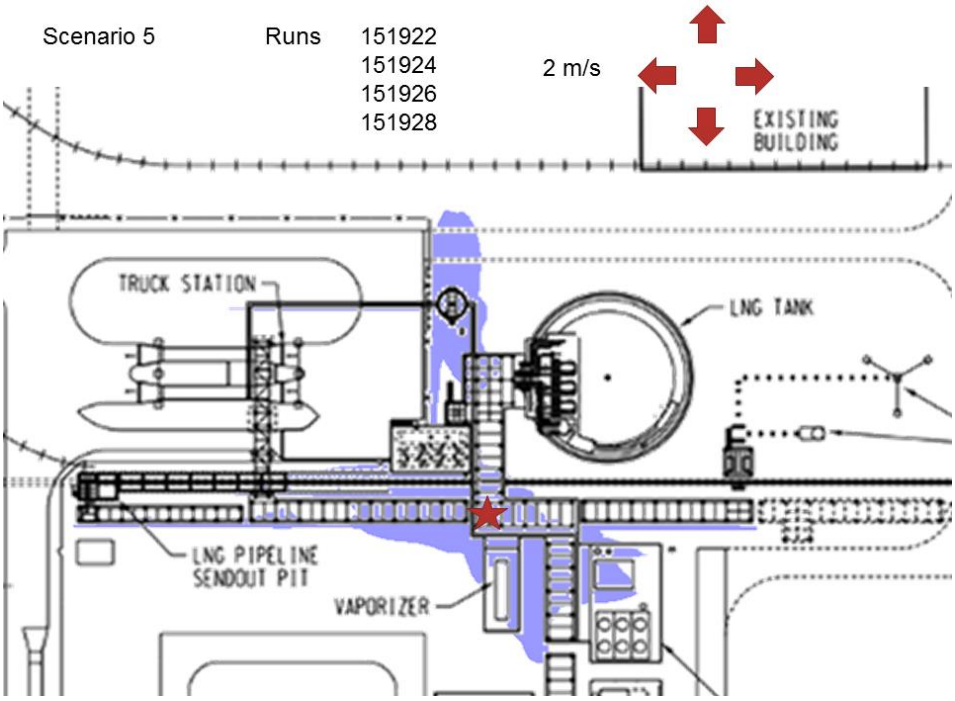

Figure 16. Footprint of the vapor clouds for an LNG spill into the header pipe trenches, with wind at 2 m/s from several directions.

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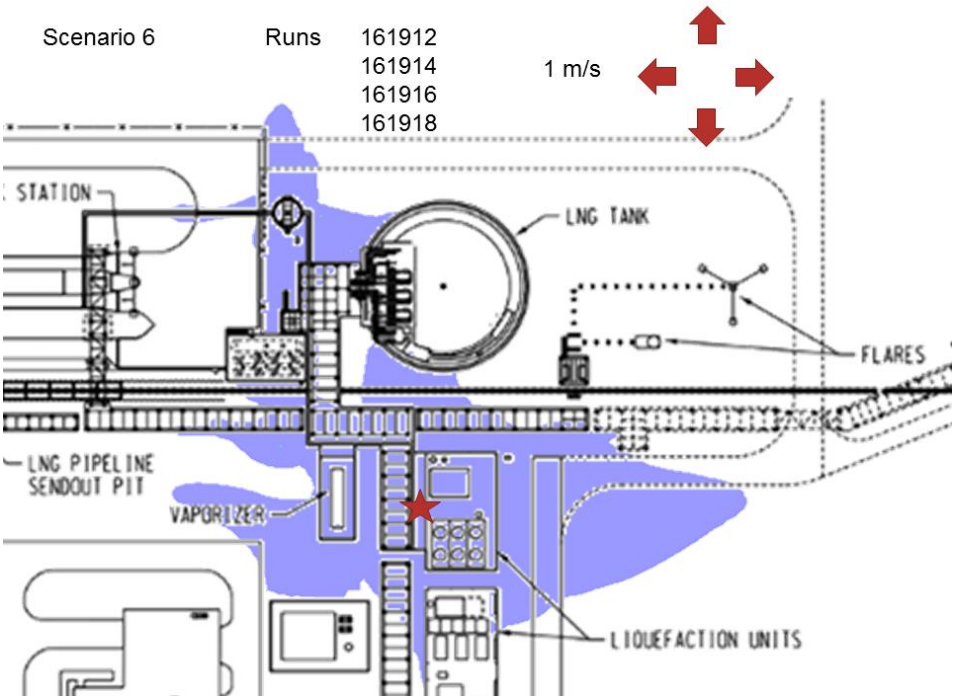

Figure 17. Footprint of the vapor clouds for an LNG spill into the rundown line trenches, with wind at 1 m/s from several directions.

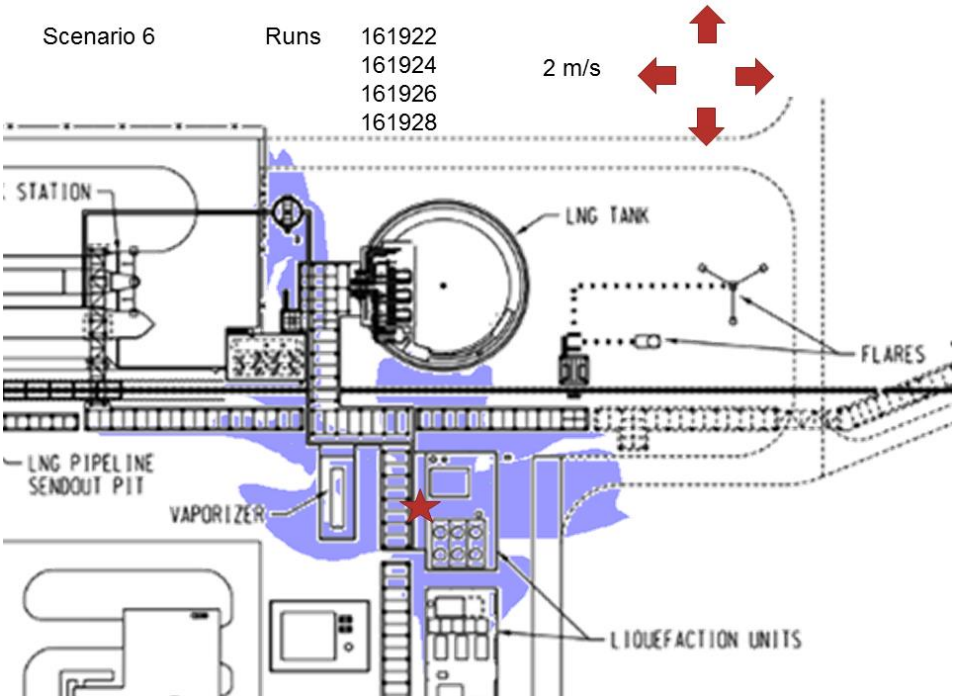

Figure 18. Footprint of the vapor clouds for an LNG spill into the rundown line trenches, with wind at 2 m/s from several directions.

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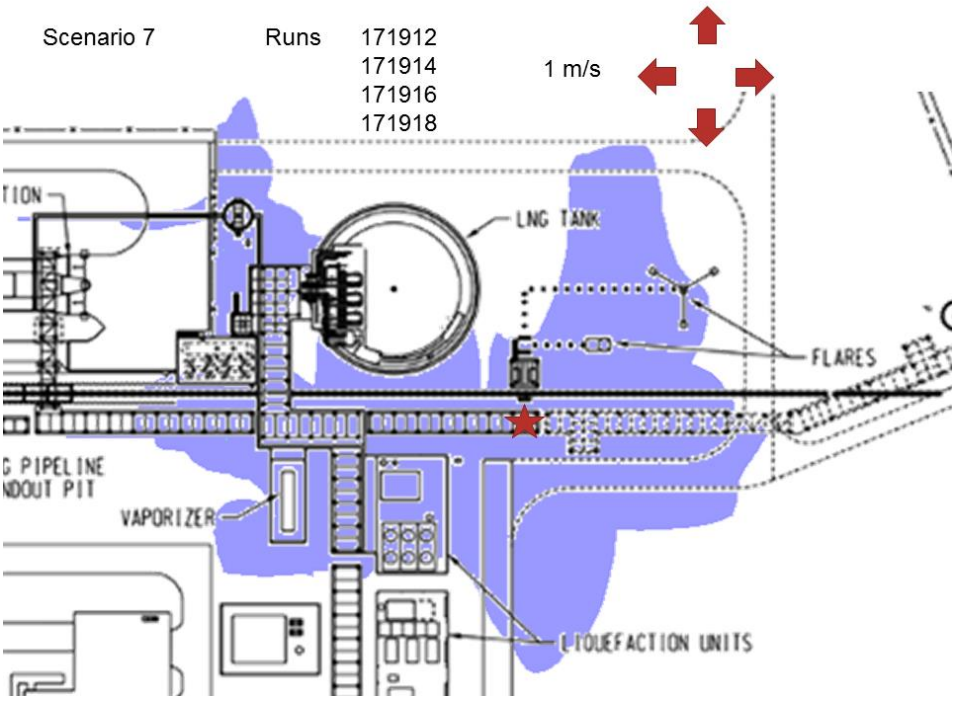

Figure 19. Footprint of the vapor clouds for an LNG spill into the HYLEBOS piperack (facility side) trenches, with wind at 1 m/s from several directions.

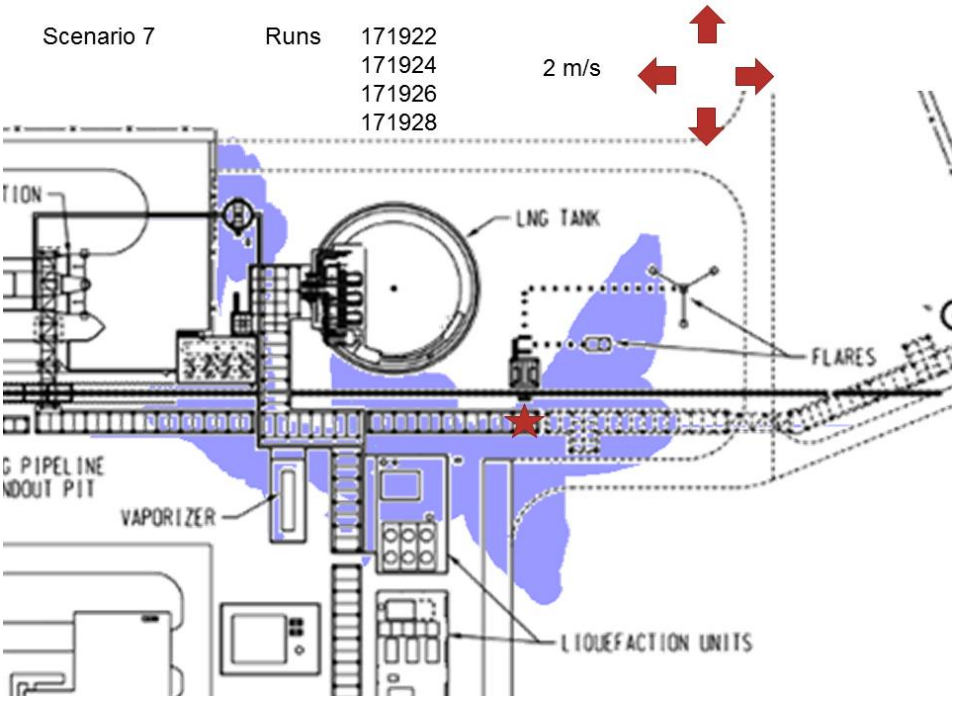

Figure 20. Footprint of the vapor clouds for an LNG spill into the HYLEBOS piperack (facility side) trenches, with wind at 2 m/s from several directions.

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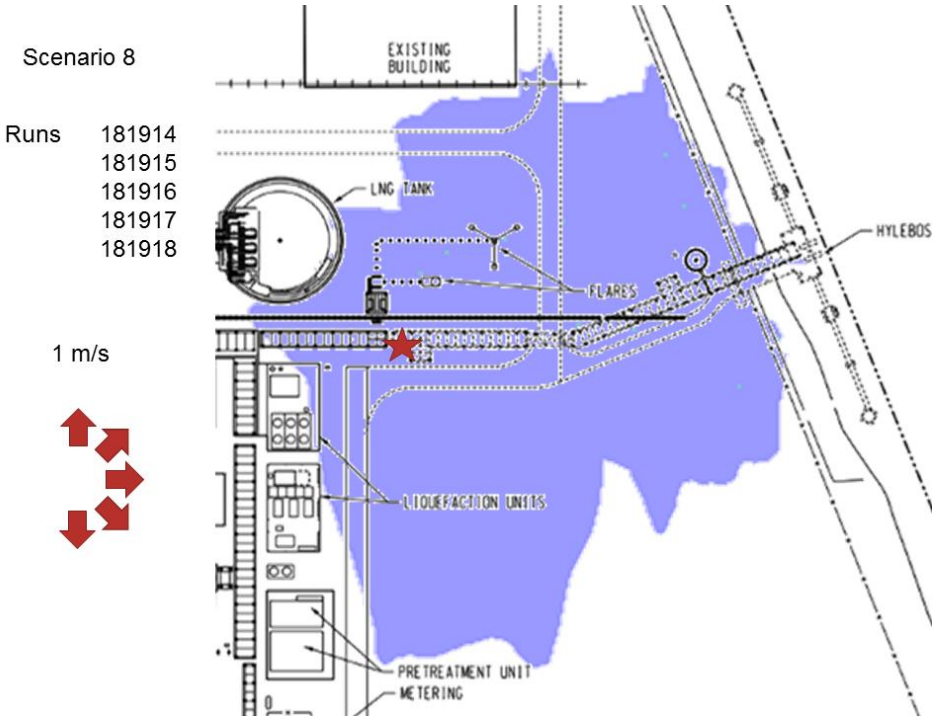

Figure 21. Footprint of the vapor clouds for an LNG spill into the HYLEBOS piperack (HYLEBOS dock side) trenches, with wind at 1 m/s from several directions.

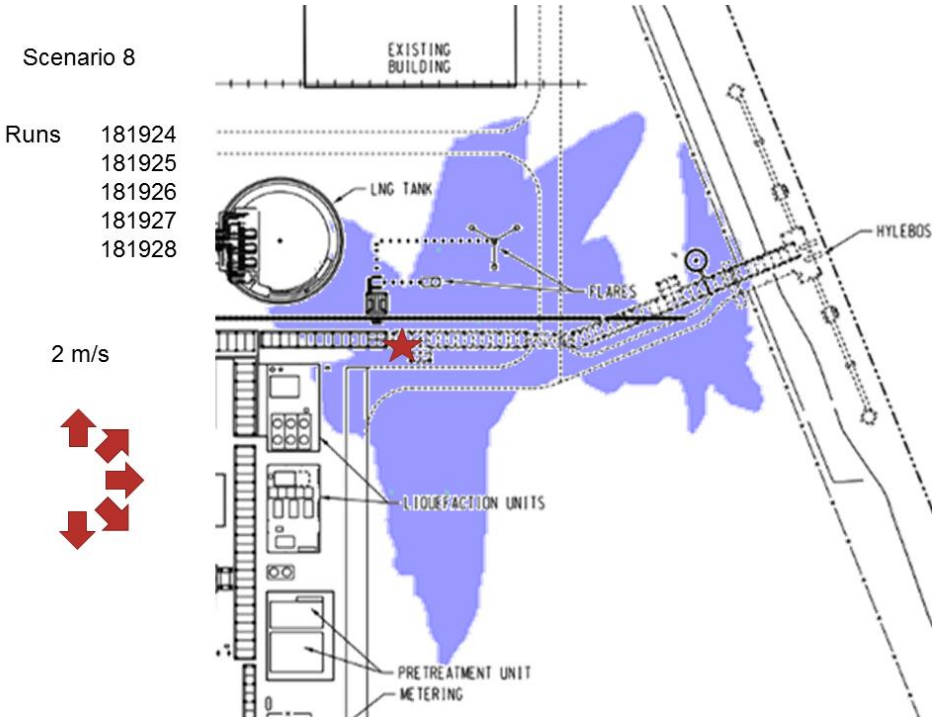

Figure 22. Footprint of the vapor clouds for an LNG spill into the HYLEBOS piperack (HYLEBOS dock side) trenches, with wind at 2 m/s from several directions.

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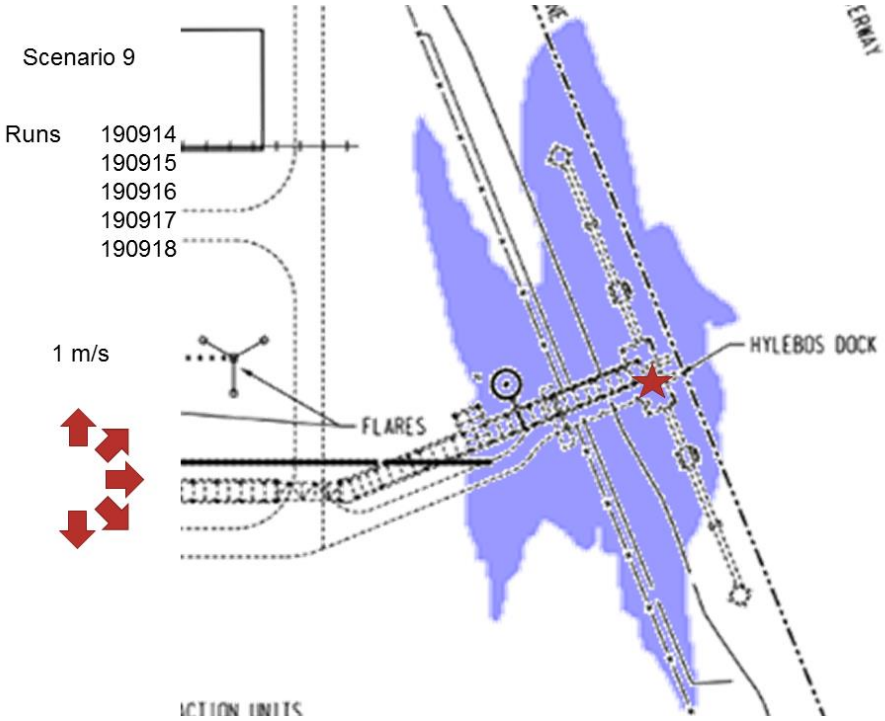

Figure 23. Footprint of the vapor clouds for an LNG spill into the HYLEBOS dock trenches, with wind at 1 m/s from several directions.

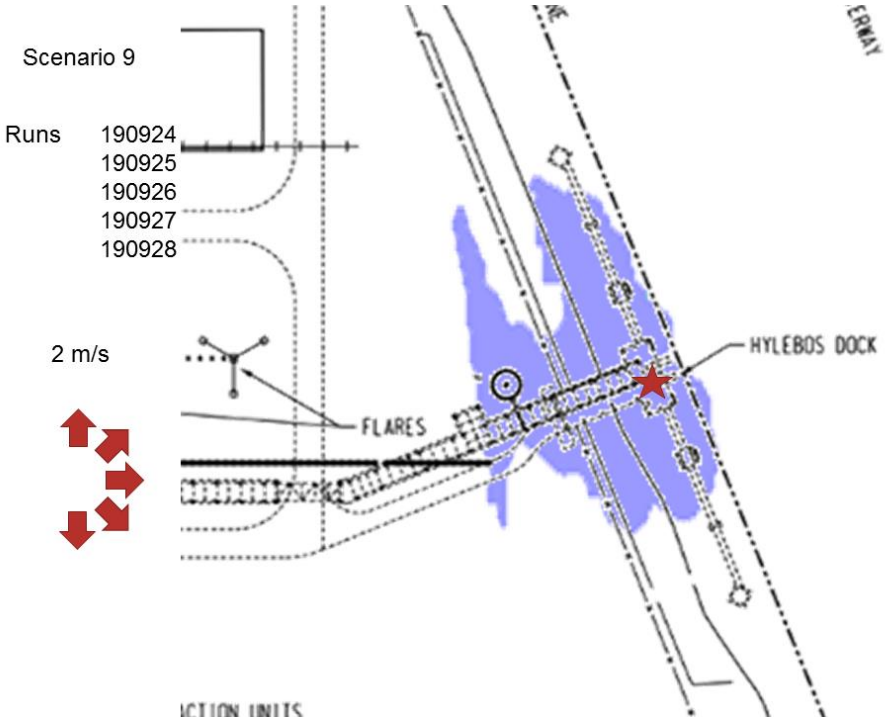

Figure 24. Footprint of the vapor clouds for an LNG spill into the HYLEBOS dock trenches, with wind at 2 m/s from several directions.

As the plots in Figure 7 through Figure 24 indicate, the vapor clouds from LNG spills remain within the property boundaries.

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3.2 Vapor Jet Releases

Federal regulations (49 CFR §193.2051 and §193.2059) require the analysis of the vapor dispersion hazards from the accidental release of flammable fluids (in this case, natural gas) to determine the potential offsite impacts. Regulations specify that provisions must be made to minimize the possibility of a flammable mixture of vapors from a specified release reaching a property line that can be built upon and that would result in a distinct hazard. The calculations presented in this report consider the ½-LFL concentration as the threshold for the flammable vapor clouds.

3.2.1 Accidental Single Leakage Source

A screening analysis of potential accidental single leakage source scenarios was performed by Chicago Bridge & Iron; the scenario specified in Table 5 was determined to require FLACS modelling.

Table 5. Single accidental leak scenarios.

Scenario ID	Location	Fluid	Pressure [psia]	Temp. [°F]	Hole Size [in.]	Leak Flow Rate [kg/s]	Elevation [ft]	Liquid Rainout [%]
NG-10	Sendout pipe	NG	40.6	64.6	10.0	20.1	3	0

3.2.2 Vapor Dispersion Simulations

The vapor dispersion hazard distances for the vapour jet release discussed in the previous section were performed using FLACS, version 9.1, and the 3D geometry model of the Tacoma LNG facility shown in Figure 2. Table 6 lists the simulations performed for the flashing jet scenario in Table 5, to evaluate sensitivity to both wind speed and direction (note that wind direction indicates where the wind is coming from). All simulations assumed a constant release rate for a duration of 10 minutes; the release was initiated after 30 seconds to allow the wind profile to stabilize (due to the presence of terrain features, buildings and other obstructions).

In all simulations, the base grid spacing in the horizontal direction was set to 5 m. Grid refinement was applied to the expanded jet (approximately 1 m in the directions perpendicular to the release). Horizontal grid stretching was performed outside the facility boundaries (in the direction of interest for cloud dispersion) and away from the release (in the crosswind and upwind direction). The vertical grid resolution was set to approximately 1 m between the ground and the release (expanded jet) and stretched upwards to the domain ceiling. All grid stretching and transitions were performed in compliance with FLACS modeling guidelines and consistent with the FLACS validation work.

Table 6. Vapor dispersion simulations for scenario NG-10 from the sendout pipe line.

Run #	Fluid	Release Location	Release Direction	Wind speed [m/s]	Wind From
200411	NG	Sendout pipe	S	1	NE
200417	NG	Sendout pipe	S	1	NW
200418	NG	Sendout pipe	S	1	N
200421	NG	Sendout pipe	S	2	NE
200427	NG	Sendout pipe	S	2	NW
200428	NG	Sendout pipe	S	2	N

The results of the FLACS vapor dispersion simulations for the releases listed in Table 6 are shown in Figure 25 and Figure 26. Each cloud is shown as the overlay of the vapor cloud footprint at each output time step. Note that most plots represent the overlay of several simulations – with different wind

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directions but same wind speed and release direction – as indicated in their respective figure captions. The approximate release location is indicated by the base of a red arrow, which points in the direction of the release; the vapor barrier is identified by a red line.

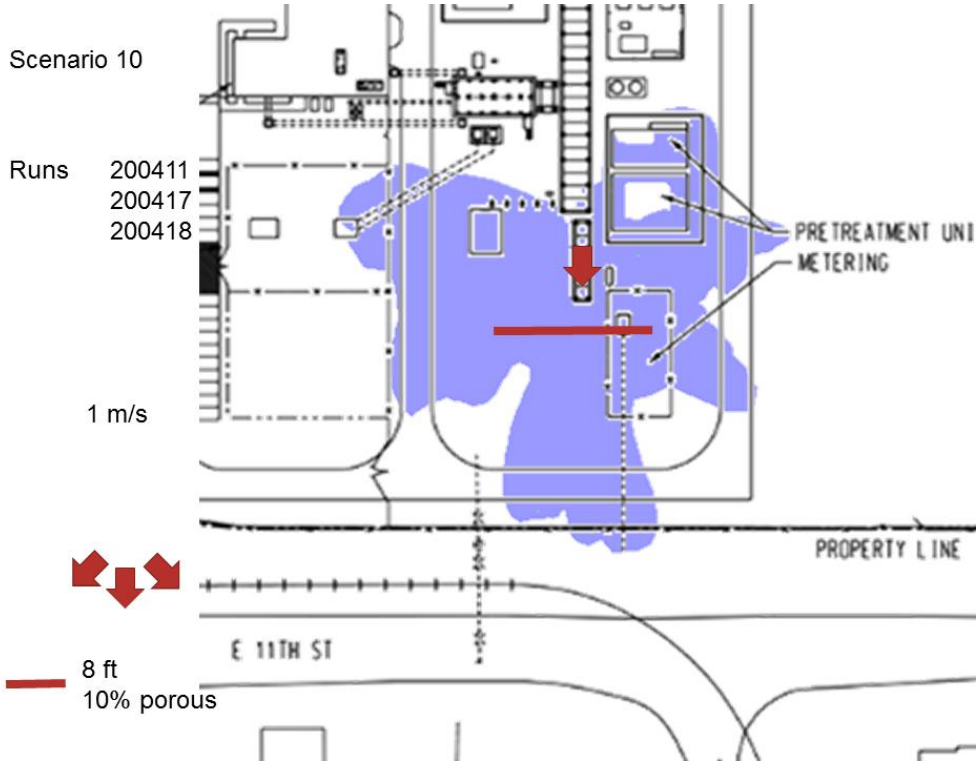

Figure 25. Vapor cloud (at ½-LFL concentration) for a release of NG from the sendout pipe (release identified by a red arrow, vapor barrier identified by a red line). Dispersion in 1 m/s wind from several directions.

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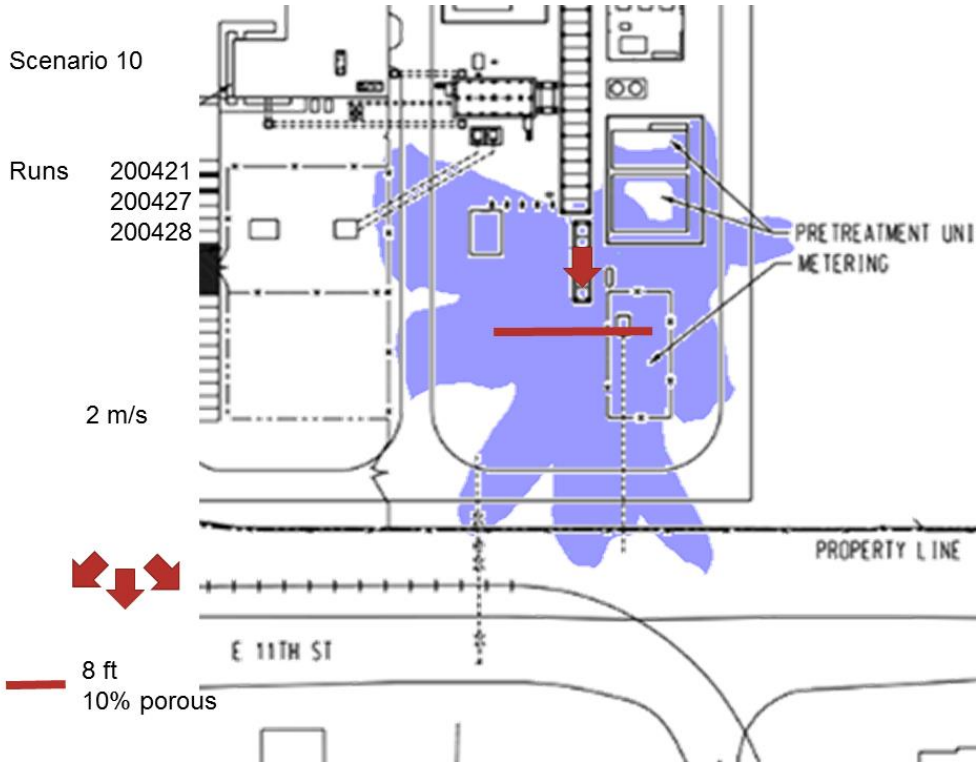

Figure 26. Vapor cloud (at ½-LFL concentration) for a release of NG from the sendout pipe (release identified by a red arrow, vapor barrier identified by a red line). Dispersion in 2 m/s wind from several directions.

As the plots in Figure 25 and Figure 26 indicate, the vapor clouds from a NG vapor release do not extend across a property line that may be built upon.

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4 Conclusions

GexCon US, Inc. (GexCon) was contacted by Chicago Bridge & Iron (CB&I) to perform a hazard analysis for the Tacoma LNG facility to be located on the port of Tacoma, Washington.

This report presents the results of the following hazard analyses:

- Flammable vapor dispersion exclusion zones for design LNG spills into the liquefaction facility trenches and sumps;
- Flammable vapor dispersion exclusion zones for a single NG vapor release within the facility.

The vapor dispersion simulations were performed using GexCon's CFD modeling software FLACS, version 9.1. FLACS was approved by the U.S. DOT as an alternate model for vapor dispersion under 49 CFR 193.2059 on October 7, 2011.

The results of the hazard analysis presented in this report are as follows:

- The footprint of the vapor dispersion cloud (to ½-LFL) for the design LNG spills remains within the property boundaries;
- The footprint of the vapor dispersion cloud (to ½-LFL) for a single NG vapor release does not extend across a property line that may be built upon.

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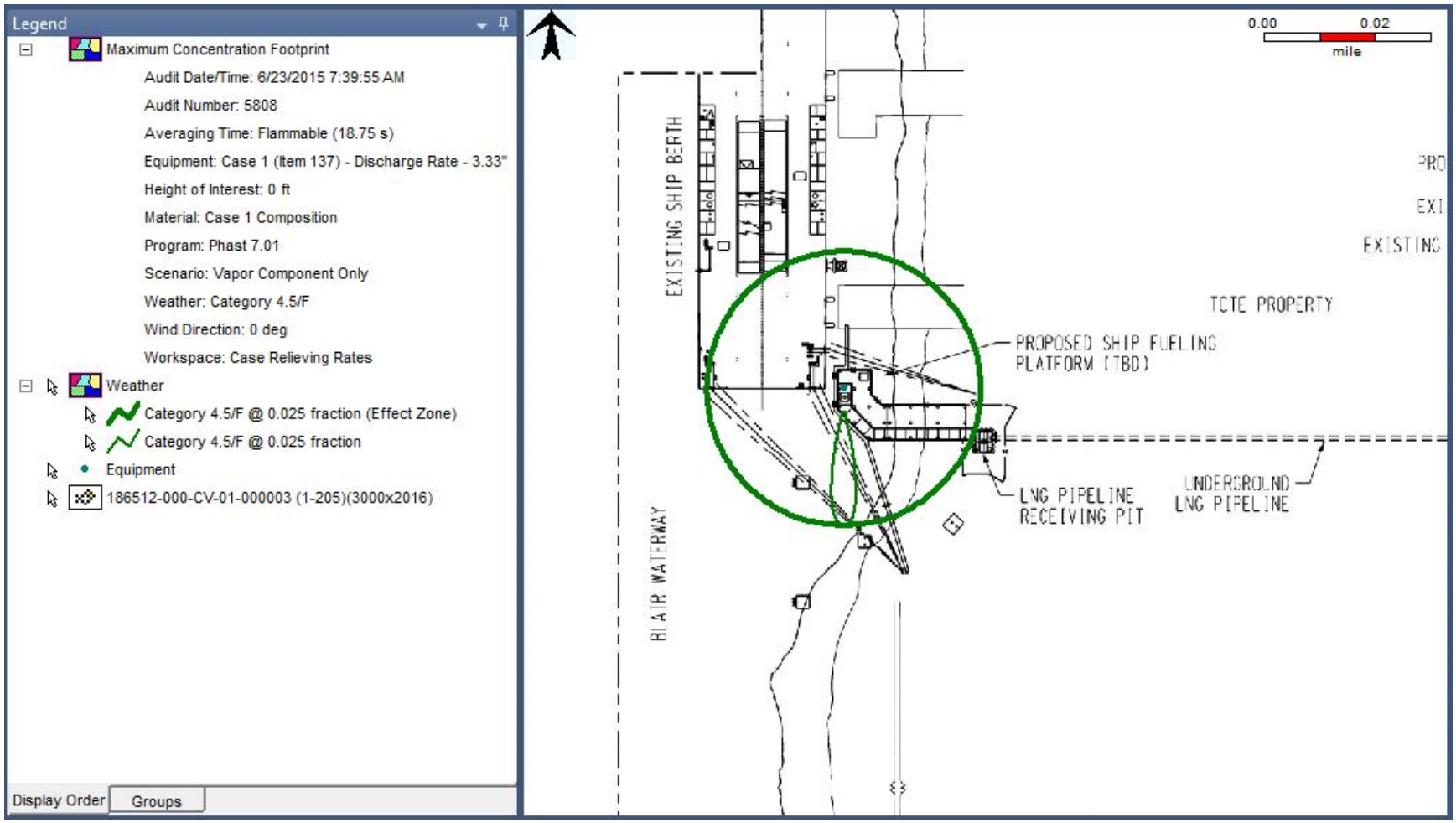
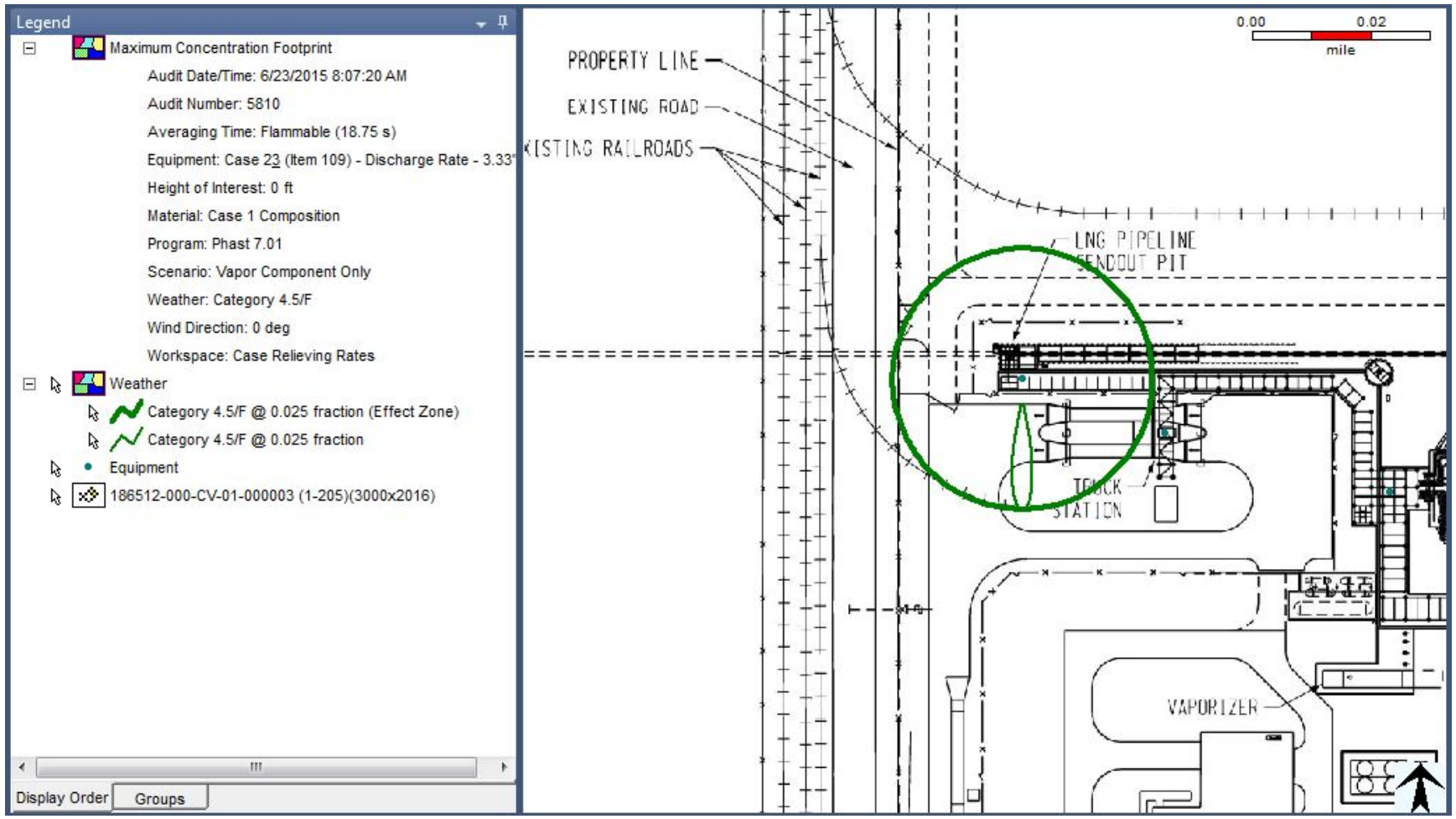
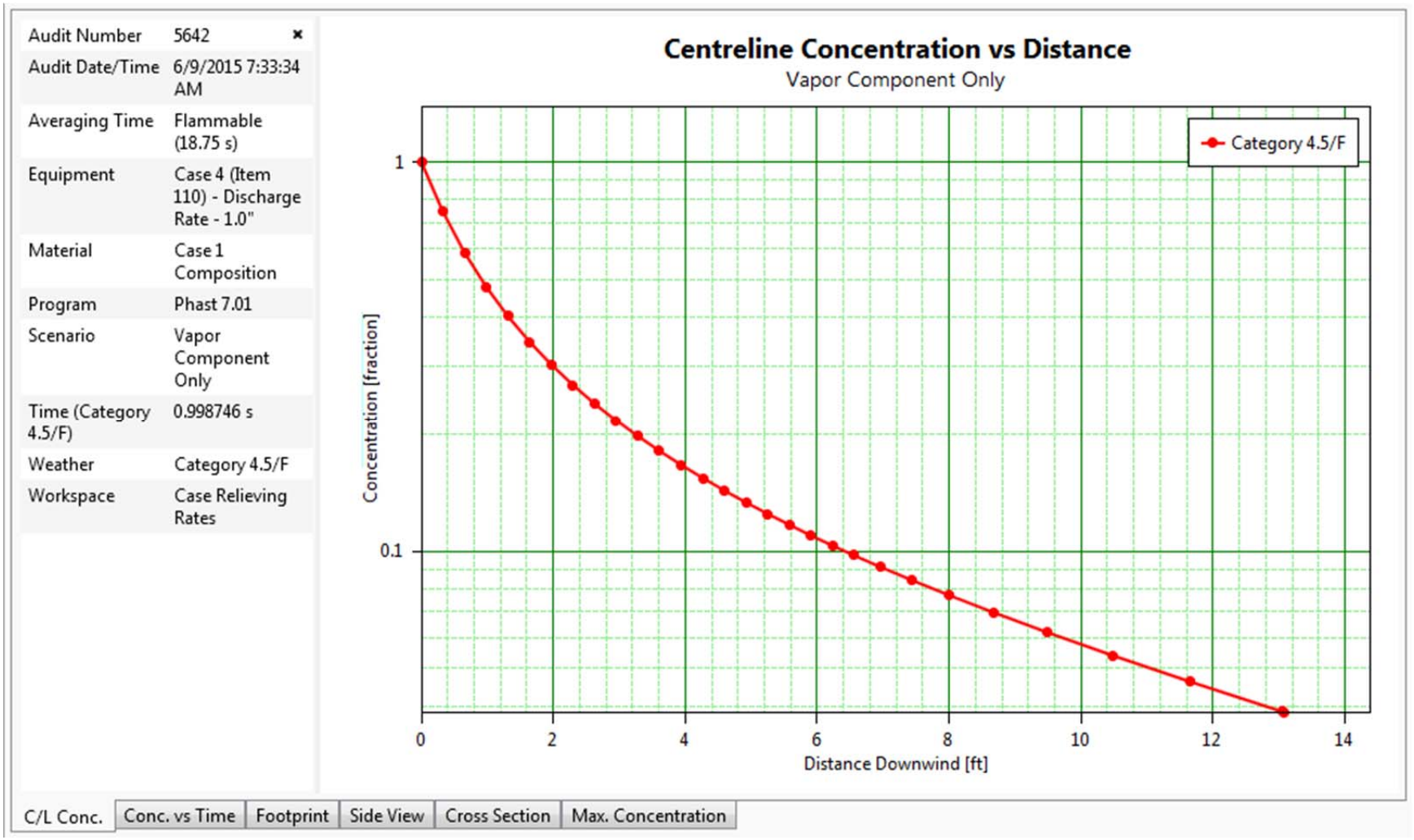
APPENDIX K – PHAST ANALYSIS RESULTS FOR VAPOR PORTION OF LNG RELEASES: VAPOR DISPERSION PLOTS



CASE 1: Flashing Vapor Release from Leak in TOTE LNG Bunkering Line on Dock

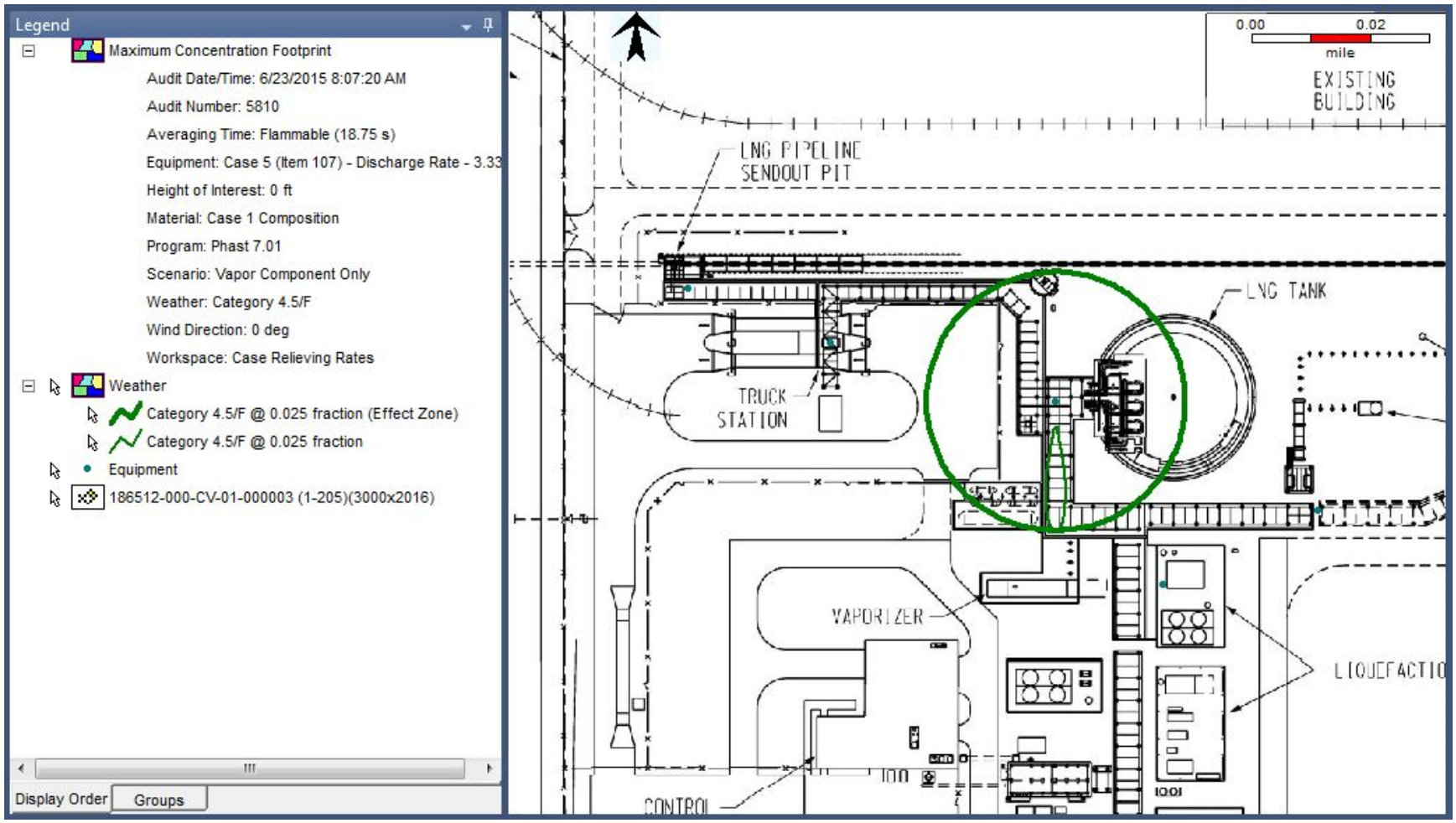


CASES 2 & 3: Flashing Vapor Release from Leak in TOTE LNG Bunkering Line Near Facility Transition Pit

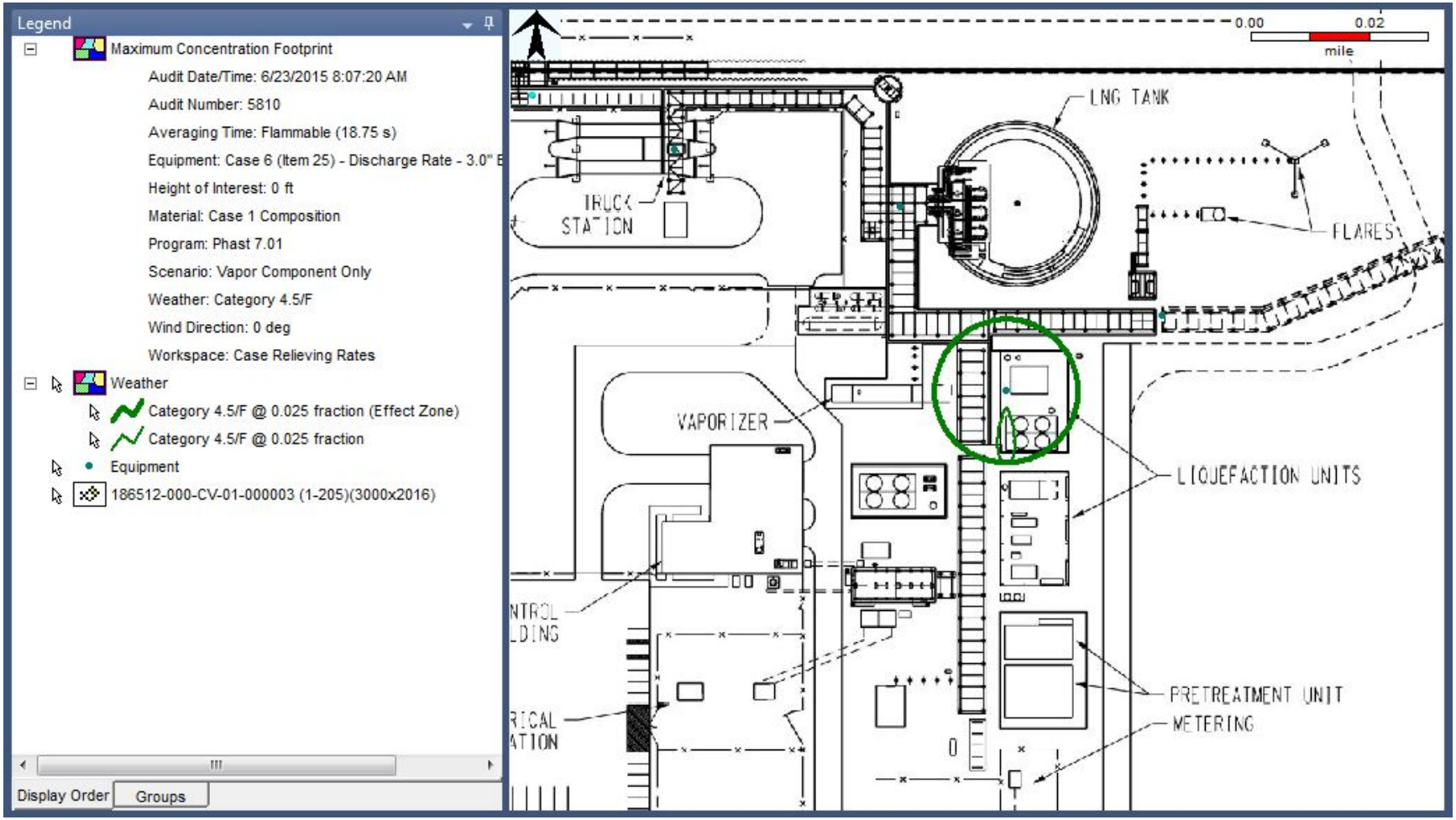


CASE 4: Flashing Vapor Release from Leak in Truck LNG Loading Line Near Truck Loading Station

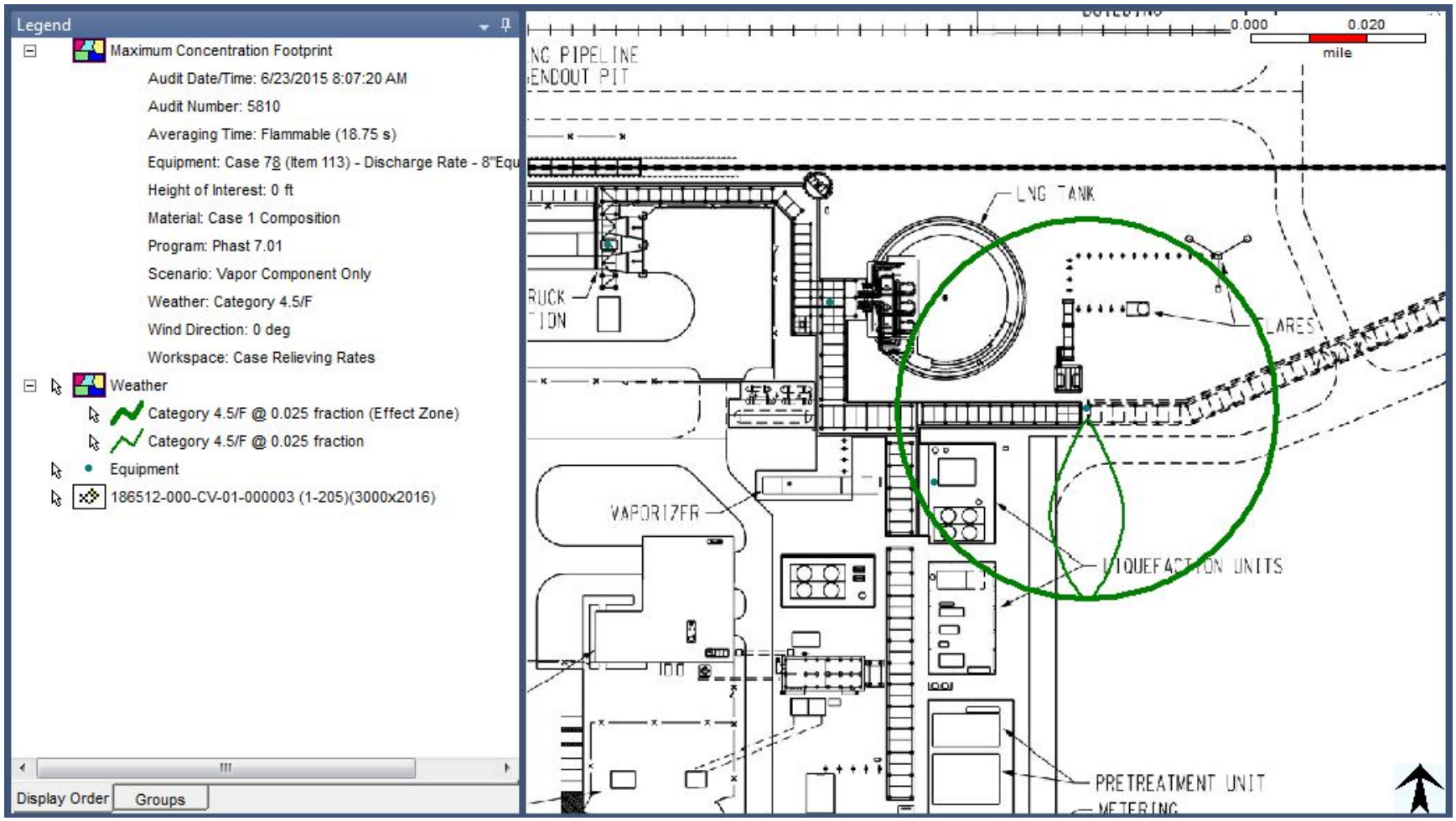
NOTE: Due to small size of vapor cloud, GIS Plot does adequately display results. Graph above shows cloud flammable concentration versus downwind distance.



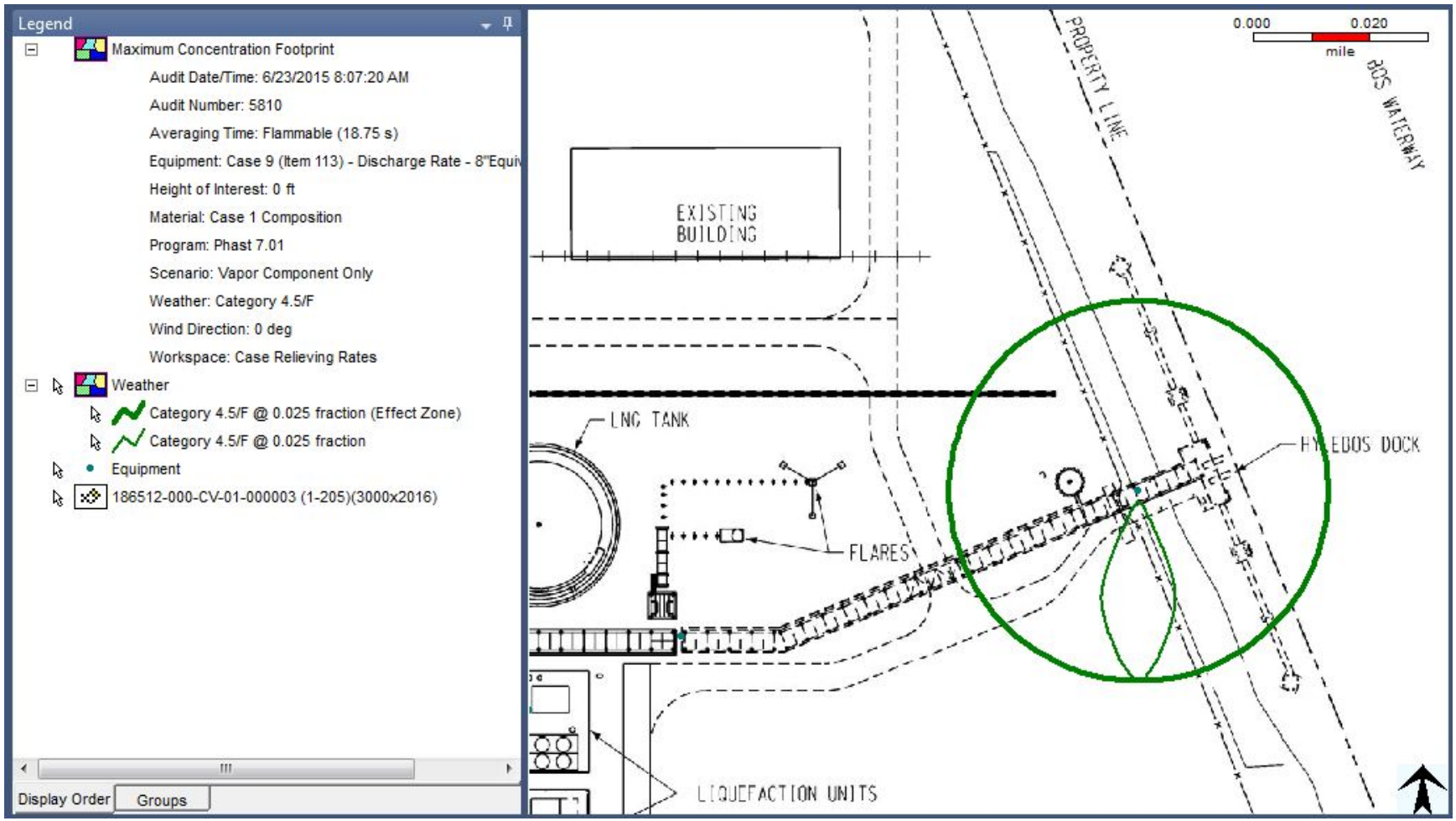
CASE 5: Flashing Vapor Release from Leak in LNG Sendout Header near Main Pipe Rack



CASE 6: Flashing Vapor Release from Leak in LNG Rundown Line in Liquefaction Area



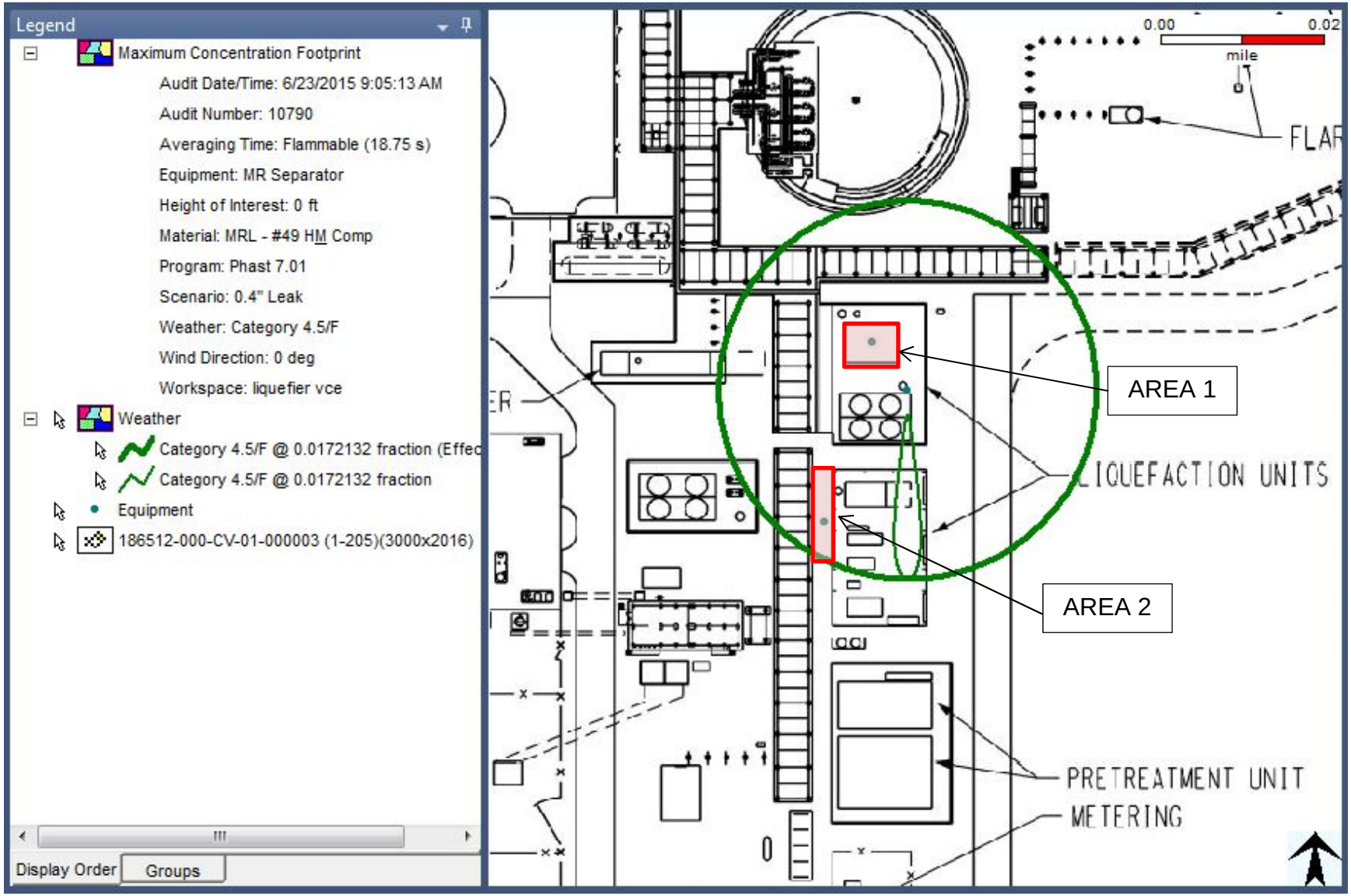
CASES 7 & 8: Flashing Vapor Release from Leak in Hylebos LNG Loading Line Near Main Pipe Rack



CASE 9: Flashing Vapor Release from Leak in Hylebos LNG Loading Line Near Hylebos Dock

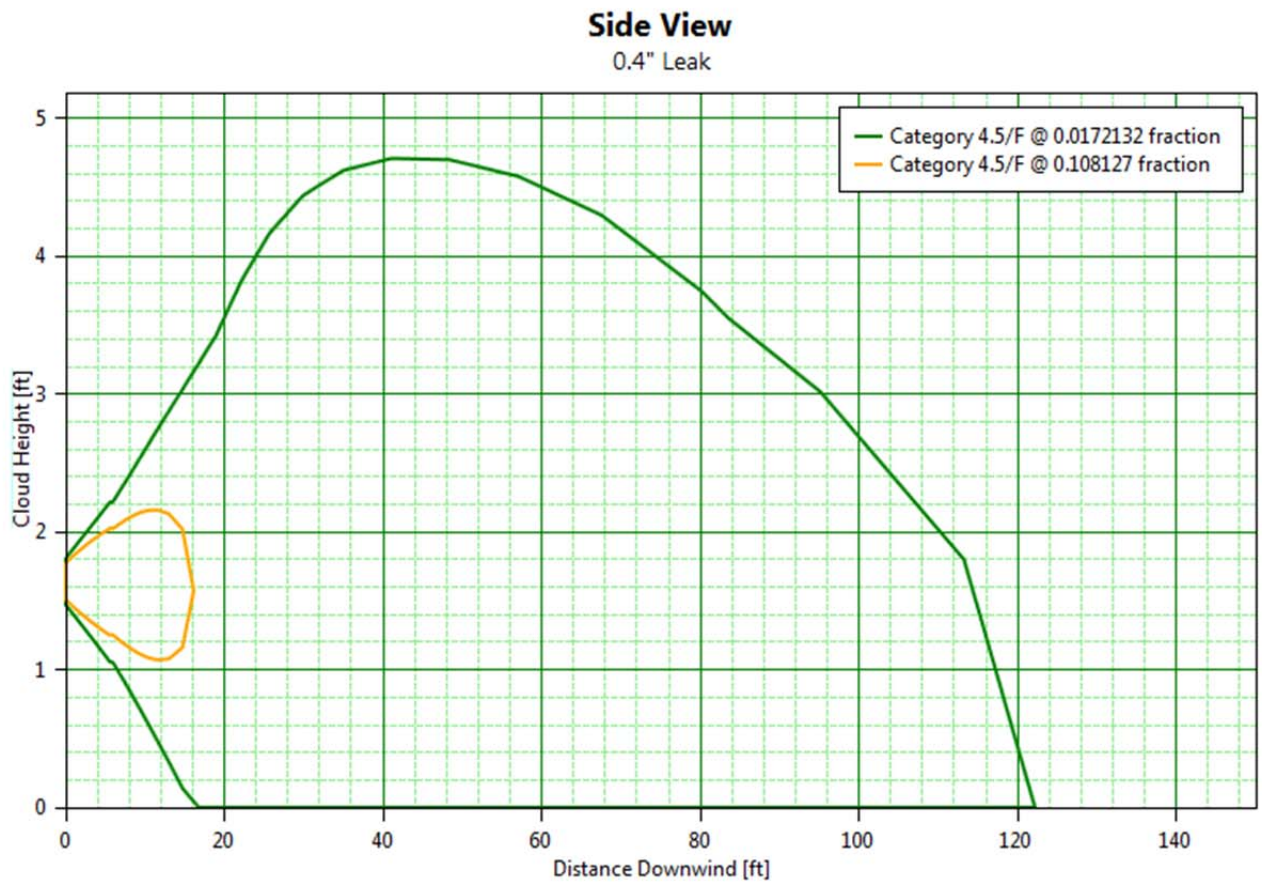
APPENDIX L – VAPOR CLOUD EXPLOSION CALCULATIONS AND PHAST ANALYSIS PLOTS

Phast Flammable Cloud & Confined Space Figures



MRL Condenser Vessel V-204: 0.4” Leak Vapor Cloud Maximum Concentration Footprint at LFL

Audit Number	10781
Audit Date/Time	6/9/2015 1:17:01 PM
Averaging Time	Flammable (18.75 s)
Equipment	MR Separator
Material	MRL - #49 H&M Comp
Offset Distance	0 ft
Program	Phast 7.01
Scenario	0.4" Leak
Time (Category 4.5/F)	37.4723 s
Weather	Category 4.5/F
Workspace	liquefier vce



MRL Condenser Vessel V-204: 0.4” Leak Vapor Cloud Height at LFL

DOCUMENT NO.: 186512-000-SE-RP-00001	REVISION: C	

Stoichiometric Ratio and Confined Space Flammable Mass Calculations

Calculate Mixture Laminar Flame Velocity

for Line MRL-11032

	Mole Frac. Stream [1] x_i	Flame Speed [2] cm/s V_{Bi}
methane	0.0779	40
ethylene	0.2377	80
propane	0.2374	46
i-pentane	0.4330	46
nitrogen	0.0140	0

mixture laminar flame velocity (LFV) 51.30 cm/s [3]

$$LFV = \frac{1}{\frac{x_1}{V_{B1}} + \frac{x_2}{V_{B2}} + \frac{x_3}{V_{B3}} + \cdots}$$

Determine Fuel Reactivity

Fuel Reactivities vs. Laminar Flame Velocity [4]

	cm/s		cm/s	
High Reactivity		LFV ≥	75	A
Medium Reactivity	75	> LFV >	45	
Low Reactivity	45	≥ LFV		

Fuel Reactivity = Medium

References

1 Composition data from Stream 49 of Design Unisim model
2 NFPA 68, 2012 ed., Annex D
3 Calculation from Eqn. 6.28 of:
"Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards", 2nd ed.
4 per Baker 1997, Pierorazio 2004

Calculation to Determine Explosion Mass for MRL Leak

Determine Stoichiometric Concentration of Fuel Required for Combustion in Air

Basis: One (1) Mole of i-Pentane in MRL Fuel

C	H	N	O	Mol. Wt.	MRL	MRL Comp.	
12.011	1.008	14.007	16	lb/lbmol		Mole Frac	Moles
1	*4*			16.0430	methane	0.0779	0.180
2	*4*			28.0540	ethylene	0.2377	0.549
3	*8*			44.0970	propane	0.2374	0.548
5	*12*			72.1510	i-pentane	0.4330	1.000
0	*0*	*2*		28.0140	nitrogen	0.0140	0.032
						MRL Fuel	1.0000
						Moles of Fuel	2.309
						Fuel Mole Weight	50.0213 lb/lbmol

Reactant Coefficients

Number of Atoms in MRL Composition per Constituent

MRL Fuel along with Oxygen are the Reactants

C	H	N	O
		2	
			2

Number of Atoms in Air per Constituent

Air	Mole Frac	Moles
nitrogen	0.78992	3.760
oxygen	0.21008	1.000
Oxygen Coefficient		**12.749**
Moles of N2 + O2		60.68

Nitrogen is Assumed to be Inert

Total Moles of Fuel-Air 62.992

Stoichiometric Concentration 0.037

C	H	N	O
1			*2*
	2		*1*
		2	

Number of Atoms in Combustion Products per Molecule

Products for Complete Combustion

STOICHIOMETRIC COMBUSTION

Products	Product Coefficients
Carbon Dioxide	7.922933
Water	9.651166
Nitrogen	47.96665

Total Number of Moles per Atom

	C	H	N	O
	0.18	0.72	0.00	0.00
	1.10	2.20	0.00	0.00
	1.65	4.39	0.00	0.00
	5.00	12.00	0.00	0.00
	0.00	0.00	0.06	0.00
	7.92	19.30	0.06	0.00
	0.00	0.00	95.87	0.00
	0.00	0.00	0.00	25.50
⟸ Moles of Oxygen Required for Complete Combustion	0.00	0.00	95.87	25.50
	7.92	19.30	95.93	25.50
⟸	7.92			15.85
⟸		19.30		9.65
⟸			95.93	
	7.92	19.30	95.93	25.50
Reaction Balance Check	0.00	0.00	0.00	0.00

1 (0.18CH4 + 0.55C2H4 + 0.55C3H8 + 1C5H12 + 0.03N2) + 12.75 (O2 + 3.76N2) ==> 7.92CO2 + 9.65H2O + 47.97N2

SUBJECT
Vapor Cloud Explosion Analysis - V-204
Tacoma LNG
Tacoma, WA

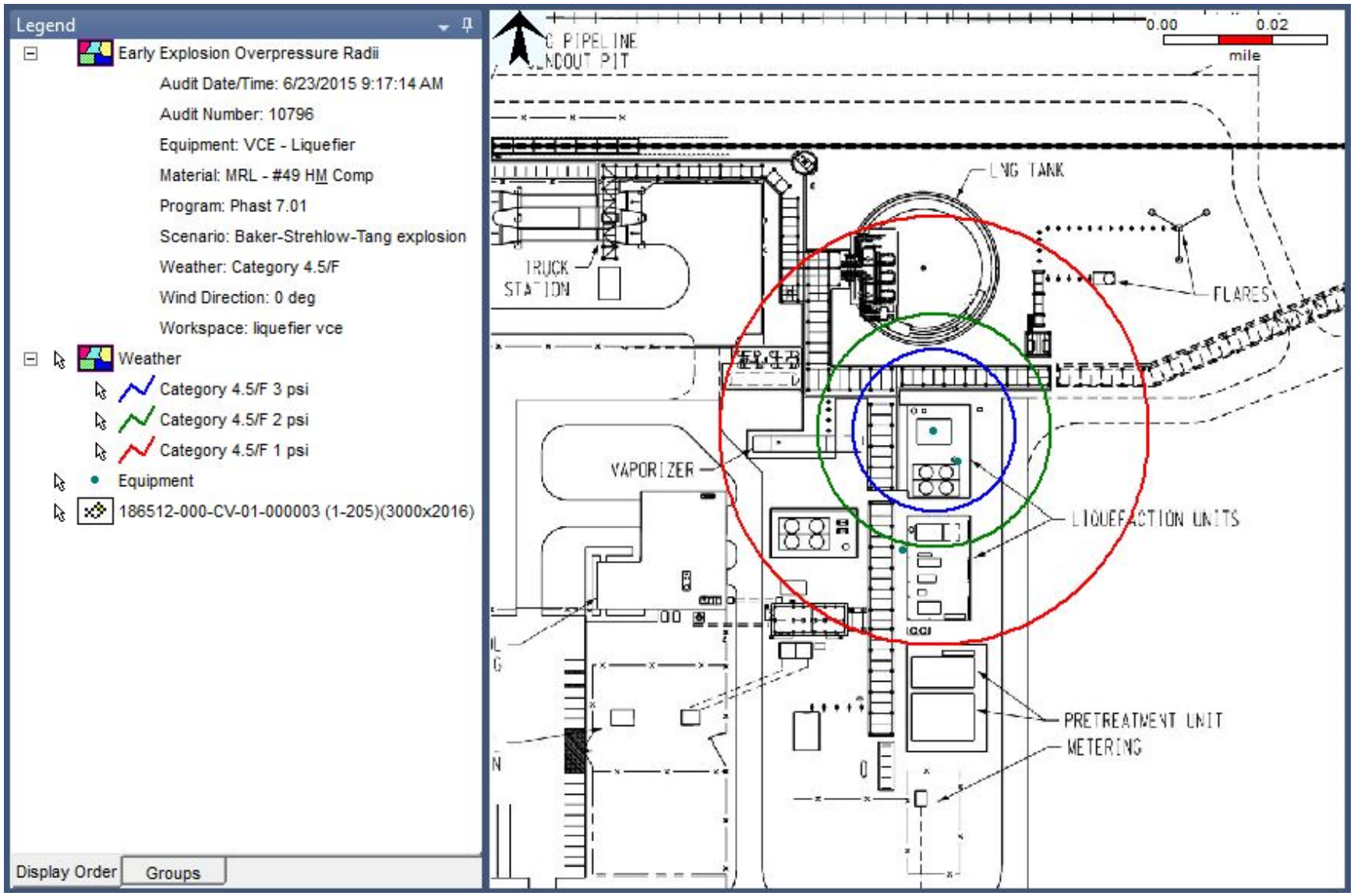
OFFICE	REVISION		REFERENCE NO.
PSE	A		186512
MADE BY / CHKD BY	MADE BY	CHKD BY	
GCB			PAGE 2 of 3
DATE: 09-Jun-15	DATE	DATE	

Calculation to Determine Explosion Mass for MRL Leak

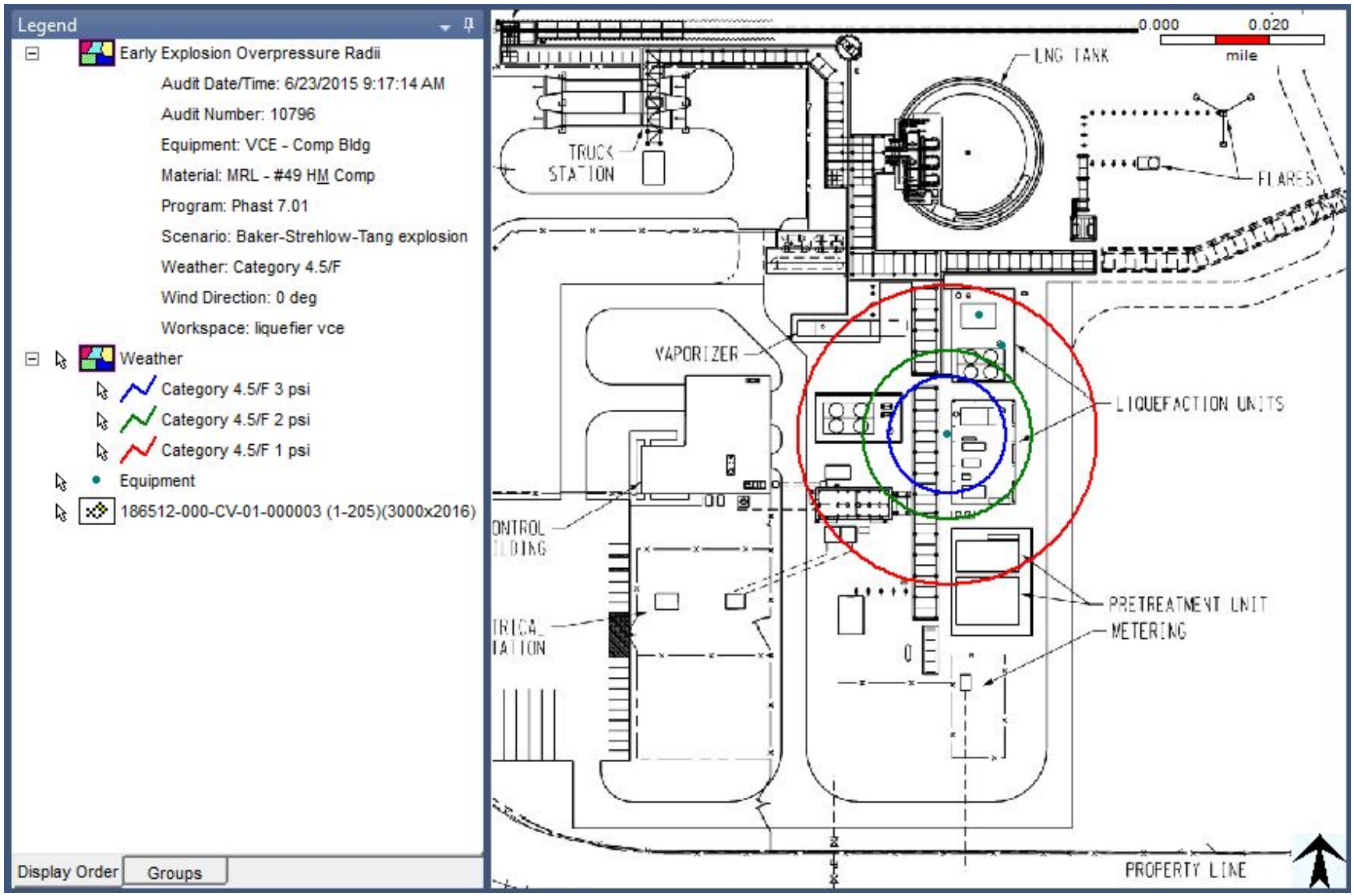
Determine Mass of Fuel Contained in Congested Areas

	Pressure	14.7	psia	design ambient condition
	Temperature	50.9	°F	design ambient condition
	Universal Gas Const.	10.73159	ft^3-psi/lbmol-R	
	Stoichiometric Concentration	3.7%	% vol fuel	
	Fuel Molar Weight	50.02	lb/lbmol	
Area #1	Total Congested Plan Area	768	ft^2	liquefaction tower plan area
	Total Congested Area Cloud Height	4.75	ft	based on V-204 0.4" leak vapor cloud results
	Total Congested Volume	3648	ft^3	
	Fuel Volume	133.7	ft^3	
	Fuel Moles in Congested Volume	0.36	lbmol	
	Vapor Cloud Fuel Mass	**17.9**	**lbs**	In Liquefaction Tower
Area #2	Total Congested Plan Area	696	ft^2	area adjacent to compressor building
	Total Congested Area Cloud Height	3	ft	based on V-204 0.4" leak vapor cloud results
	Total Congested Volume	2088	ft^3	
	Fuel Volume	76.6	ft^3	
	Fuel Moles in Congested Volume	0.21	lbmol	
	Vapor Cloud Fuel Mass	**10.3**	**lbs**	Adjacent to Compressor Building

Phast Vapor Cloud Explosion Overpressure Plots



Area 1: Vapor Cloud Explosion Overpressure Plot



Area 2: Vapor Cloud Explosion Overpressure Plot

APPENDIX M – CLIMATE DATA

Radiation and Vapor Dispersion Analysis Weather Data

Weather conditions at Tacoma/McChord Air Force Base, Washington were chosen to be representative of the weather conditions at the Tacoma LNG facility site in the Port of Tacoma. McChord AFB is approximately 11 miles southwest of the site, which is the closest weather station for which ASHRAE data has been compiled. ASHRAE weather station data sheets provide a complete and reliable set of climatic data for use in engineering design. The data sheet for Tacoma/McChord AFB was published in the 2013 edition of the ASHRAE Fundamentals Handbook.

Radiation Calculations

Section 193.2057.(b) of 49 CFR Part 193 states, "In calculating exclusion distances, the wind speed producing the maximum exclusion distances shall be used except for wind speeds that occur less than 5% of the time based on recorded data for the area."

From the Tacoma/McChord AFB data sheet, the extreme annual wind speed which is not exceeded more than 5% of the time = 15.6 mph maximum wind velocity.

Section 193.2057.(c) of 49 CFR Part 193 states, "The ambient temperature and relative humidity that produce the maximum exclusion distances shall be used except for values that occur less than 5% of the time based on recorded data for the area."

For radiation calculations, lower ambient temperatures and lower relative humidity produces maximum exclusion distances. From the Tacoma/McChord AFB data sheet, the coldest average monthly temperature occurred in December and was 38.8°F. The 5% Dry Bulb Mean Daily Temperature Range was 13.7°F. Subtracting half of the range from the average produces a temperature of 31.95°F. This provides a conservative estimate of the temperature not exceeded more than 5% of the time annually, as only data from the coldest average month is considered.

The relative humidity is determined by averaging the relatively humidity values derived from the 5% Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures.

The following will be used for radiation calculations:
Wind speed = 15.6 mph, maximum
Relative Humidity = 54.7%
Ambient temperature = 31.95°F

Vapor Dispersion Calculations

Section 193.2058.(b).(2) of 49 CFR Part 193 states, "Dispersion conditions are a combination of those which result in longer predicted downwind dispersion distances than other weather conditions at the site at least 90% of the time, based on figures maintained by National Weather Service of the U.S. Department of Commerce, or as an alternative where the model used gives longer distances at lower wind speeds, Atmospheric Stability (Pasquill Class) F, wind speed = 4.5 mph (2.01 m/s) at reference height of 10m, relative humidity = 50% and atmospheric temperature = average in the region."

From the Tacoma/McChord AFB data sheet, the annual average dry bulb temperature is 50.9°F.
The model being used results in longer distances at lower wind speeds.

The following will be used for vapor dispersion calculations:
Atmospheric Stability = Pasquill Class F
Wind Speed = 4.5 mph (2.01 m/s) at reference height of 10m
Relative Humidity = 50%
Atmospheric Temperature = 50.9°F

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TACOMA/MC CHORD AFB, WA, USA

WMO#: **742060**

Lat: **47.15N** Long: **122.48W** Elev: **285** StdP: **14.54** Time Zone: **-8 (NAP)** Period: **00-09** WBAN: **99999**

Annual Heating and Humidification Design Conditions

	Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		
				99.6%			99%			0.4%		1%				
		99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	
(1)	**12**	**21.3**	**25.0**	**13.6**	**11.1**	**26.9**	**19.0**	**14.4**	**29.1**	**26.4**	**46.7**	**23.5**	**44.7**	**2.0**	**160**	(1)

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

	Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
			0.4%		1%		2%		0.4%		1%		2%				
			DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(2)	**7**	**23.4**	**86.3**	**64.4**	**82.2**	**63.2**	**79.2**	**61.9**	**66.2**	**82.7**	**64.4**	**79.2**	**63.0**	**76.3**	**7.6**	**20**	(2)

	Dehumidification DP/MCDB and HR								Enthalpy/MCDB						Hours
	0.4%			1%			2%		0.4%		1%		2%		8 to 4 &
	DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	55/69
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)
(3)	**60.8**	**80.3**	**69.3**	**58.9**	**75.0**	**68.2**	**57.2**	**70.4**	**67.0**	**30.9**	**83.3**	**29.5**	**79.2**	**28.5**	**76.5**	**1125**	(3)

Extreme Annual Design Conditions

	Extreme Annual WS			Extreme Max	Extreme Annual DB				n-Year Return Period Values of Extreme DB								
					Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years		
	1%	2.5%	5%	WB	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(4)	**20.3**	**17.7**	**15.6**	**73.0**	**14.9**	**94.1**	**4.1**	**4.5**	**12.0**	**97.3**	**9.6**	**100.0**	**7.3**	**102.5**	**4.3**	**105.8**	(4)

Monthly Climatic Design Conditions

				Annual (d)	Jan (e)	Feb (f)	Mar (g)	Apr (h)	May (i)	Jun (j)	Jul (k)	Aug (l)	Sep (m)	Oct (n)	Nov (o)	Dec (p)	
(5)	**Temperatures, Degree-Days and Degree-Hours**		Tavg	**50.9**	**39.7**	**40.8**	**44.3**	**48.2**	**54.7**	**60.1**	**65.3**	**64.1**	**58.9**	**50.9**	**43.7**	**38.8**	(5)
(6)			Sd		**6.20**	**4.34**	**4.79**	**4.85**	**5.28**	**5.07**	**4.87**	**3.76**	**4.38**	**5.08**	**5.89**	**6.13**	(6)
(7)			HDD50	**1473**	**324**	**258**	**186**	**91**	**14**	**0**	**0**	**0**	**1**	**49**	**201**	**349**	(7)
(8)			HDD65	**5288**	**785**	**678**	**641**	**503**	**321**	**165**	**53**	**63**	**190**	**438**	**639**	**812**	(8)
(9)			CDD50	**1784**	**4**	**0**	**11**	**38**	**161**	**302**	**474**	**437**	**266**	**77**	**12**	**2**	(9)
(10)			CDD65	**123**	**0**	**0**	**0**	**0**	**3**	**18**	**62**	**34**	**6**	**0**	**0**	**0**	(10)
(11)			CDH74	**2211**	**0**	**0**	**0**	**13**	**110**	**385**	**923**	**599**	**179**	**2**	**0**	**0**	(11)
(12)			CDH80	**669**	**0**	**0**	**0**	**1**	**28**	**124**	**320**	**158**	**38**	**0**	**0**	**0**	(12)
(13)	**Precipitation**		PrecAvg	**39.8**	**6.4**	**4.0**	**3.6**	**2.8**	**1.7**	**1.5**	**0.8**	**1.0**	**1.8**	**4.0**	**6.2**	**6.1**	(13)
(14)			PrecMax	**47.7**	**11.1**	**9.5**	**6.5**	**5.0**	**4.2**	**3.4**	**2.1**	**4.2**	**5.4**	**7.4**	**10.8**	**10.6**	(14)
(15)			PrecMin	**28.9**	**1.3**	**1.3**	**0.5**	**1.0**	**0.7**	**0.2**	**0.1**	**0.0**	**0.4**	**0.5**	**1.1**	**2.3**	(15)
(16)			PrecSD	**5.0**	**2.5**	**2.2**	**1.5**	**1.1**	**0.9**	**1.0**	**0.7**	**1.4**	**1.4**	**1.8**	**2.6**	**2.3**	(16)
(17)	**Monthly Design Dry Bulb and Mean Coincident Wet Bulb Temperatures**	0.4%	DB	**58.7**	**59.0**	**66.5**	**75.1**	**83.9**	**88.7**	**94.8**	**89.5**	**84.5**	**72.3**	**61.3**	**57.2**	(17)
(18)			MCWB	**54.9**	**48.0**	**55.3**	**56.9**	**61.8**	**63.6**	**68.6**	**66.4**	**63.0**	**57.5**	**56.1**	**53.9**	(18)
(19)		2%	DB	**54.6**	**54.7**	**61.1**	**68.2**	**76.7**	**83.8**	**87.7**	**84.1**	**79.0**	**66.4**	**57.3**	**52.4**	(19)
(20)			MCWB	**51.5**	**46.9**	**51.0**	**54.2**	**59.5**	**62.4**	**66.1**	**63.7**	**61.7**	**57.3**	**52.8**	**49.4**	(20)
(21)		5%	DB	**51.9**	**52.1**	**56.8**	**63.4**	**71.8**	**78.8**	**82.3**	**81.0**	**74.8**	**63.5**	**55.0**	**50.0**	(21)
(22)			MCWB	**49.7**	**45.9**	**48.8**	**51.8**	**57.4**	**60.8**	**64.2**	**62.9**	**59.9**	**55.2**	**50.9**	**47.3**	(22)
(23)		10%	DB	**48.5**	**49.6**	**54.1**	**59.3**	**66.2**	**72.7**	**79.0**	**76.9**	**71.7**	**60.7**	**53.7**	**47.7**	(23)
(24)			MCWB	**46.5**	**44.9**	**47.4**	**49.5**	**55.4**	**58.8**	**62.4**	**61.4**	**59.1**	**54.4**	**49.9**	**45.4**	(24)
(25)	**Monthly Design Wet Bulb and Mean Coincident Dry Bulb Temperatures**	0.4%	WB	**55.6**	**51.4**	**56.5**	**58.1**	**63.6**	**66.0**	**70.9**	**68.1**	**64.5**	**62.1**	**57.3**	**54.8**	(25)
(26)			MCDB	**58.7**	**55.3**	**65.0**	**72.1**	**80.5**	**84.6**	**91.7**	**84.7**	**79.6**	**66.0**	**59.5**	**57.1**	(26)
(27)		2%	WB	**52.5**	**48.6**	**52.9**	**55.4**	**60.2**	**63.2**	**67.2**	**65.2**	**62.5**	**59.1**	**54.3**	**50.3**	(27)
(28)			MCDB	**53.7**	**51.7**	**58.4**	**65.7**	**73.3**	**80.0**	**84.9**	**80.9**	**75.5**	**64.4**	**57.2**	**52.1**	(28)
(29)		5%	WB	**49.3**	**46.6**	**50.3**	**53.0**	**58.3**	**61.5**	**65.4**	**63.6**	**61.4**	**56.8**	**52.2**	**47.4**	(29)
(30)			MCDB	**50.6**	**49.6**	**55.0**	**60.5**	**68.8**	**76.6**	**80.8**	**77.7**	**73.1**	**61.5**	**54.6**	**49.0**	(30)
(31)		10%	WB	**46.5**	**45.7**	**48.0**	**51.0**	**56.4**	**59.6**	**63.5**	**62.3**	**59.7**	**54.9**	**49.9**	**45.5**	(31)
(32)			MCDB	**48.0**	**48.4**	**52.7**	**58.0**	**65.1**	**71.8**	**76.6**	**74.7**	**69.2**	**59.3**	**52.2**	**46.8**	(32)
(33)	**Mean Daily Temperature Range**		MDBR	**12.4**	**17.1**	**16.6**	**19.2**	**19.9**	**20.1**	**23.4**	**23.4**	**22.7**	**17.5**	**14.4**	**12.2**	(33)
(34)		5% DB	MCDBR	**14.3**	**21.8**	**23.0**	**27.7**	**30.7**	**32.9**	**31.8**	**32.0**	**31.4**	**23.1**	**15.7**	**13.7**	(34)
(35)			MCWBR	**10.6**	**14.4**	**13.8**	**15.3**	**15.3**	**14.6**	**13.2**	**14.4**	**16.2**	**13.9**	**11.1**	**10.4**	(35)
(36)		5% WB	MCDBR	**12.3**	**17.0**	**19.4**	**24.3**	**24.8**	**28.2**	**28.2**	**26.6**	**27.1**	**17.7**	**13.2**	**12.4**	(36)
(37)			MCWBR	**9.7**	**12.0**	**12.5**	**13.6**	**13.0**	**13.3**	**12.1**	**12.7**	**14.6**	**11.6**	**10.3**	**10.3**	(37)
(38)	**Clear Sky Solar Irradiance**	taub		**0.333**	**0.315**	**0.323**	**0.331**	**0.331**	**0.324**	**0.319**	**0.325**	**0.342**	**0.339**	**0.323**	**0.317**	(38)
(39)		taud		**2.569**	**2.614**	**2.540**	**2.471**	**2.447**	**2.464**	**2.511**	**2.546**	**2.520**	**2.546**	**2.622**	**2.614**	(39)
(40)		Ebn,noon		**241**	**275**	**288**	**294**	**296**	**297**	**298**	**292**	**277**	**260**	**245**	**235**	(40)
(41)		Edh,noon		**20**	**22**	**28**	**32**	**34**	**34**	**32**	**30**	**28**	**24**	**18**	**17**	(41)

Nomenclature: See separate page